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The Maine  
Agricultural Experiment  
Station  
ORONO

BULLETIN 381

APRIL, 1936

The Bionomics and Control of  
Wireworms in Maine ✓



FIELD SHOWING DESTRUCTION CAUSED BY WIREWORMS

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AGRICULTURAL EXPERIMENT STATION  
ORONO, MAINE

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## BULLETIN 381

# THE BIONOMICS and CONTROL of WIREWORMS IN MAINE \*

JOHN H. HAWKINS

### PURPOSE OF THIS BULLETIN

It is the purpose of this bulletin to present some of the results obtained during several years of study of wireworms. It is hoped that these results may be of interest both to those who are concerned in the practical problem of wireworm control and to those whose chief interest is in the details of the bionomics of wireworms. The material of a practical nature is printed in larger type than that of a more technical nature. The preceding table of contents is offered as a guide in the selection of the topics which may be of special interest to the readers.

### HISTORICAL

The young of the family Elateridae, which are now commonly called wireworms, were designated as larvae or grubs by Harris (1862, p. 52-53), who says: "In England they are called wireworms, from their slenderness and uncommon hardness. They are not to be confounded with the American wireworm, a species of *Julus*, which is not a true insect, but belongs to the class Myriopoda, a name derived from the great number of feet with which most of the animals included in it are furnished; whereas the English wire-worm has only six feet." Harris evidently refers to the English definition of wireworm given by Westwood (1839, p. 237), who designates the larvae of *Agriotes lineatus* L. and *Agriotes obscurus* L. as wireworms because of their cylindrical form and hardness of texture. The term wireworm was used by Curtis (1860, p. 153) to include eleven species of the genus *Elater* as erected by Linneaus. Roberts (1919, p. 119) discusses the mean-

\* Also presented to the faculty of the Graduate School of Cornell University, June, 1935, as a thesis under the title "The Wheat Wireworm *Agriotes mancus* Say with Notes on Some Other Injurious Elaterids" in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

ing of the word wireworm and says in part: "Since, however, the word has been so generally used in recent years to denote the larva of any injurious Elaterid, it seems undesirable to define it any more closely than did Curtis, but to use it as applying primarily to the genus *Agriotes* and that of *Athous haemorrhoidalis* F. The larvae of other species of Elaterids may eventually also have to be included. . . ."

The term wireworm as used in the recent entomological literature of North America denotes any larva of the family Elateridae, especially those injurious to vegetation. There is a tendency in certain New England localities to designate the common millepedes found in fields and gardens as wireworms or sometimes black wireworms. This may be accounted for as a remaining influence of Harris's writings. Millepedes with elongate, cylindrical bodies and exceptionally hard cuticula are in fact more aptly called wireworms than are some of the elaterid larvae whose bodies are flattened or irregular in shape and relatively soft and pliable. The word wireworm is used in this paper in its general sense, that is, as including all or any of the larvae of the family Elateridae. Generic and specific names are used whenever it is possible to supply them. This is done in order to avoid the confusion which sometimes arises when all species of Elaterid larvae are designated as wireworms, because measures which are satisfactory in the control of certain species do not necessarily apply in the control of certain others. For instance the wheat wireworm, *Agriotes mancus* Say, cannot be controlled by the same methods employed against the Great Basin wireworm, *Ludius pruininus* Horn.

More than half a century ago wireworms were discussed in the entomological literature of this country by Walsh (1866), Riley (1866), and Fitch (1867). Experimental work with wireworms was initiated at Cornell University by Comstock and Slingerland (1891). The published results of these experiments long constituted the standard of recommendations for the control of wireworms, and today still remain a pertinent source of information on the subject. Wireworms and their control in the Mississippi Valley were discussed by Forbes (1892) and some excellent illustrations are to be found in his paper. He discussed at length the natural enemies, prevention, and control of wireworms. Chittenden (1902) appears to be the first entomologist of the United States

Department of Agriculture to publish a bulletin on the subject, wireworms. During more recent years numerous federal and state publications have added useful information on the subject of wireworms and their control.

Three decades ago a report of wireworms in Maine was made by Patch (1905) who said: "As the present season has brought an unusual number of complaints against wireworms the following statement was published as a newspaper article." The foregoing quotation refers to an article discussing wireworms and their control and implies that there were complaints previous to the publication of the article. Wireworm injury to crops at LaGrange, Maine, was reported by Johannsen (1910) and wireworm injury to corn was described by Johannsen and Patch (1911). In the same publication are recorded some experimental data which they obtained on wireworm control. This was the first experimental work done on wireworm control in Maine, according to available records. These experiments, started in 1911, were continued the next year by Johannsen (1912). Again in 1918 and 1920 newspaper articles published by the Maine Agricultural Experiment Station appeared and wireworms continued to be a source of annoyance to farmers and gardeners. Finally at the spring meeting of 1926 a project on wireworm control was authorized by the Experiment Station Council. The project was given the title "Wireworm Control" and was initiated in May of 1926 as a field experiment in the use of calcium cyanide for control of wireworms. In August the writer assumed responsibility for the project on wireworm control. Since that time the project has been enlarged to include other phases of the problem. Studies of the morphology of Elateridae, the identification of the species involved, ecology, life history, and general biology of wireworms have been found to be necessary adjuncts of wireworm control. Field investigations have been carried on in conjunction with laboratory experiments and study. In the following pages are recorded data obtained during about eight years of wireworm investigations in Maine.

#### THE ECONOMIC IMPORTANCE OF WIREWORMS

Houser (1932, p. 33) discusses white grubs and wireworms and says in part: "Flint and Metcalf estimate the annual loss

caused by insects to hay, corn, and potatoes at nearly \$417,000,000 per year. A classical example of the neglected problem, particularly in areas in America where grass is an item in crop rotation, is that of the white grubs and wireworms.

"The losses caused by both of these insects for the most part are not spectacular—indeed, in many instances, they are precisely the opposite and frequently pass unnoticed. The work performed in the past has indicated that to barely approach an adequate solution is a task involving many years of patient effort. The single fact that, as a rule, three years or more are required to complete the life cycle injects into the problem the long time element in no uncertain manner.

"Still another obstruction involved in the problem is the great difficulty experienced in securing data pertaining to the insects themselves that precision seems to demand, because they lead a subterranean existence during the greater part of the life cycle. Any scheme devised thus far is not without its weaknesses, since there is likely to enter into the situation elements of unnaturalness or disturbance to such an extent that the results secured may not be dependable."

The annual monetary loss caused to agricultural crops of Maine by wireworms amounts to a considerable sum. Planted seeds are destroyed, growing plants are killed, and tuber or root crops are often injured so badly that when mature they are unfit for market. Injury by wireworms is often hidden and easily overlooked. For this reason they may be confused with injury caused by other organisms. In fields where many plants are growing, a considerable number of plants may be destroyed by wireworms and the damage pass unnoticed because of the relatively greater number of plants unaffected. Estimates of losses due to reductions of crop yields are apt to be unreliable. Labor and money losses because of wireworm attacks are also obscure, for often no accounts are kept of money and labor expended on crops destroyed or injured. Because of the reasons mentioned above it would be easy to underestimate damages done to crops by wireworms.

The most important field crops of Maine had a combined value of \$44,442,000 for 1930 (Table 1). All of these crops are injured to some extent by wireworms, although the injury to buckwheat, beans, and peas is slight. The total value of the corn crop

for 1930 exceeded \$2,000,000. During that year certain areas of corn were wholly destroyed and much more injury, not so apparent to the casual observer, was done by minor wireworm attacks on the seed and growing plants.

TABLE 1

*Production and Value of Some Important Maine Crops (1930)\**

Crops	Production	Value
Corn for grain	84,000 Bus.	\$84,000
Corn for silage	86,000 Tons	396,000
Corn for forage	10,000 Tons	40,000
Wheat	44,000 Bus.	46,000
Oats	4,740,000 Bus.	2,465,000
Barley	96,000 Bus.	78,000
Buckwheat	180,000 Bus.	144,000
Hay, all	872,000 Tons	9,495,000
Beans dry	112,000 Bus.	491,000
Potatoes	45,250,000 Bus.	29,412,000
Beans for canning	3,500 Tons	203,000
Corn for canning	48,800 Tons	1,283,000
Peas for canning	2,992,000 Lbs.	105,000
	Total	\$44,242,000

\* Data furnished by Mr. W. E. Schrumpf, of the Department of Agricultural Economics, Maine Agricultural Experiment Station.

There is no way of estimating the loss that is annually caused to the hay crop of Maine by wireworms. The hay crop of the State was valued at more than \$9,000,000 during 1930. Although it is not generally known that the hay crop is injured by wireworms, it is a fact that wireworms attack and destroy the two common meadow grasses, timothy and red top. Wireworms affect both the quantity and quality of the hay crop of Maine. Wheat, oats, and barley are also sometimes seriously affected. Not only are field crops of Maine injured by wireworms, but market gardens, ornamental plantings, and home gardens are also affected. (A list of food plants of elaterid larvae in Maine, p. 6.)

The following list is of plants observed by the writer to be affected by wireworms in Maine. The list is of those plants injured under outdoor conditions only and is based entirely upon field observations. There are doubtless many other plants that should be included in the list of food plants of wireworms in Maine, although it will probably be a long time before they are all known.

## FOOD PLANTS OF ELATERID LARVAE IN MAINE

## CAMPANULACEAE

Balloon-flower. *Platycodon grandiflorum* A.DC.

## CARYOPHYLLACEAE

*Gypsophila* sp.

## CHENOPodiaceae

Beet. *Beta vulgaris* L.

Spinach. *Spinacia oleracea inermis* Peterm.

## COMPOSITAE

Aster. *Aster* sp.

Endive. *Cichorium endivia* L.

Dahlia. *Dahlia* sp.

*Gaillardia* sp.

Common Dandelion. *Taraxacum officinale* L.

## CRUCIFERAE

Charlock. *Brassica arvensis* L.

Wild Rutabaga. *Brassica campestris* L.

Rutabaga. *Brassica napobrassica* Mill.

Cauliflower. *Brassica oleracea* L. var. *botrytis* L.

Cabbage. *Brassica oleracea* L. var. *capitata* L.

Wild Radish. *Raphanus raphanistrum* L.

Cultivated Radish. *Raphanus sativus* L.

## CUCURBITACEAE

Muskmelon (fruit). *Cucumis melo* L.

Cucumber. *Cucumis sativus* L.

Winter Squash (roots and fruit). *Cucurbita maxima*

Duchesne.

Pumpkin (fruit). *Cucurbita pepo* L.

## GRAMINEAE

Quack, quitch or couch grass. *Agropyron repens* L.

Redtop. *Agrostis alba* L.

Foxtail Grass. *Alopecurus* sp.

Oat. *Avena sativa* L.

Barnyard Grass. *Echinochloa crusgalli* L.

Barley. *Hordeum vulgare* L.

Timothy. *Phleum pratense* L.

Rye. *Secale cereale* L.

Wheat. *Triticum sativum* Lam.

Corn. *Zea mays* L.

## LEGUMINOSAE

Cultivated Lupine. *Lupinus* sp.

Bush Lima Bean. *Phaseolus limensis* L. var. *limenanus* Bailey.

Common Bean. *Phaseolus vulgaris* L. var. *humilis* Alef.

Garden Pea. *Pisum sativum* L.

Alsike Clover. *Trifolium hybridum* L.

Red Clover (stem on soil). *Trifolium pratense* L.

Vetch (seed in the soil). *Vicia* sp.

## LILIACEAE

Onion. *Allium cepa* L.

## PINACEAE

White Pine (logs, beneath bark). *Pinus strobus* L.

## PLANTAGINACEAE

Common Plantain. *Plantago major* L.

## POLEMONIACEAE

Cultivated Phlox. *Phlox* sp.

## POLYGONACEAE

Common Buckwheat. *Fagopyrum esculentum* Gaertn.

## RANUNCULACEAE

Cultivated Columbine. *Aquilegia* sp.

## ROSACEAE

Strawberry. *Fragaria* sp.

Apple (fruit on ground and beneath bark of tree). *Pyrus malus* L.

## SOLANACEAE

Tomato. *Lycopersicon esculentum* Mill.

Eggplant. *Solanum melongena* L.

Potato. *Solanum tuberosum* L.

## UMBELLIFERAE

Cultivated Carrot. *Daucus carota* L. var. *sativa* DC.

The greatest annual loss caused to the crops of Maine by wireworms is that caused to potatoes. The loss caused by these insects to that part of the 1930 potato crop which was inspected amounted to nearly \$4,000,000.<sup>1</sup>

<sup>1</sup> Date furnished by Mr. C. M. White, Chief, Division of Markets, Maine State Department of Agriculture. Data represented in Table 2 are for the 1930 crop which was shipped during 1930 and 1931. Mr. White estimated losses by deducting the price for which potatoes injured by wireworms could be sold from that of potatoes not injured.

TABLE 2

*Monetary Loss Due to Wireworm Injury to Potatoes 1930-1931*

Station	Total Loss
Caribou and West Caribou	\$73,423.55
Dover-Foxcroft	61,941.87
Easton	12,740.96
Fort Kent	18,643.38
Frenchville	16,582.94
Goodrich	12,070.16
Limestone	30,102.74
Masardis	2,497.04
Patten	6,138.43
Presque Isle and West Presque Isle	59,923.81
St. Francis	5,089.35
St. Luce	7,998.72
Sherman	14,912.03
Squa Pan	1,250.79
Stockholm	1,289.82
Sweden	5,095.54
Thornedike	12,438.11
Van Buren	16,971.30
Washburn	24,852.72
Total	\$383,963.26

The total shipment of potatoes by rail for the season was 53,381 carloads. Of these, 5,457 carloads or about 10.2 per cent of the potatoes shipped by rail were inspected. It is reasonable to assume that the potatoes not inspected were damaged by wireworms to the same extent as those inspected. Generally, potatoes fairly free from injuries are more likely to be offered for inspection than are those more severely injured. The loss to the entire crop shipped during 1930 by rail, estimated on the basis of the loss caused by wireworms to that part of the crop inspected before shipment, amounts to about \$3,760,000. This does not include the loss caused by wireworms to those potatoes shipped by truck, or sold for consumption in the State.

Data for the season 1930-31 were chosen in making an estimate of the damage done to the potato crop of Maine by wireworms, because more extensive figures were obtainable for this period than for other periods. The season 1930-31 happened to be a season of severe wireworm damage to potatoes and, since potatoes were sold for a fair price, the cash value of the losses caused was comparatively great. The loss in barrels on account of wireworm injury to potatoes inspected at shipping points during 1930-31 was

approximately 204,000 barrels, or about 561,000 bushels.<sup>2</sup> Potato production for the State during 1930-31 was estimated at 45,250,000 bushels. During 1934 the crop was 56,280,000 bushels. Unless good cultural practices are maintained there is no apparent reason why wireworm injury to potatoes cannot again equal that of 1930 in proportion by volume, if not in monetary loss.

The annual loss caused by wireworms to field crops, vegetables, and ornamental plants of Maine is of economic importance and the many ways in which these pests injure plants make them exceedingly annoying as well as destructive. It is probable that the annual loss to all crops grown in the State during any year would reach \$1,000,000 and when wireworm infestations are especially severe, the loss would be several times that amount.

#### DISTRIBUTION OF WIREWORMS

Wireworm control is necessary to the successful production of crops in almost every important agricultural region of the world. They are destructive to cereals and vegetables in Great Britain, Germany, Russia, and other European nations. They attack crops in Asia, Japan, and Australia. Wireworms are reported as agricultural pests in Argentine and Brazil and they injure sugar cane, cotton, and tobacco in many of the warm regions of the earth.

Wireworms are well known pests of field and truck crops of the Eastern Canadian Provinces. They also attack wheat and other crops in Western Canada and are especially destructive to wheat in the great wheat-producing districts of this area.

Wireworm injury is caused to crops over the greater part of the United States. For example: alfalfa, sugar beets, and truck crops are affected by wireworms in California. Grain and potatoes are sometimes injured in Oregon, and the wheat crop of the Great Basin Region of the Northwest is sometimes seriously damaged by wireworms. Wireworms are injurious to agricultural crops in Montana, Minnesota, and the Dakotas. They are reported as injurious in practically all the states of the Mississippi Valley and southward and westward to Texas. Crops of the states bordering the Great Lakes are affected by wireworms, as are all those of the Atlantic seaboard.

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<sup>2</sup> Data furnished by Mr. C. M. White, Chief, Division of Markets, State Department of Agriculture. |

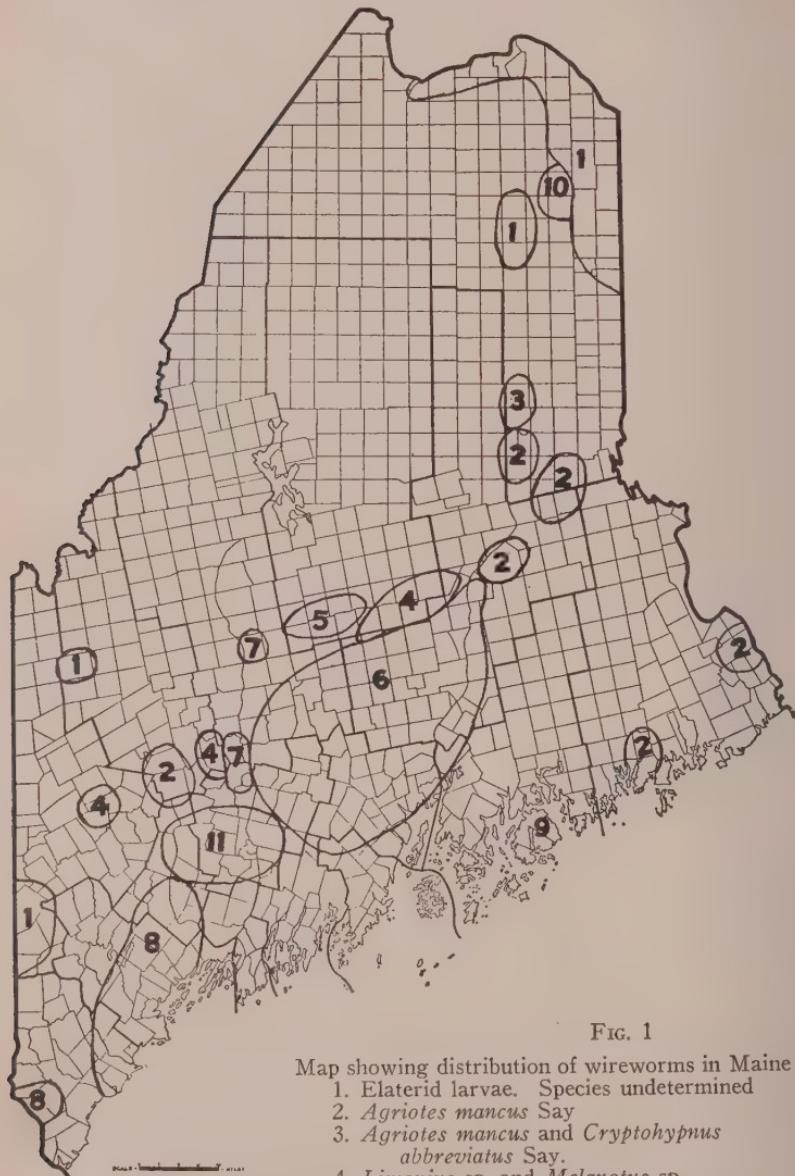


FIG. 1

- Map showing distribution of wireworms in Maine
1. Elaterid larvae. Species undetermined
  2. *Agriotes mancus* Say
  3. *Agriotes mancus* and *Cryptohypnus abbreviatus* Say.
  4. *Limonius* sp. and *Melanotus* sp.
  5. *Agriotes mancus*, *Ludius* sp. and *Limonius* sp.
  6. *Agriotes mancus*, *Melanotus* sp. and *Limonius* sp.
  7. *Melanotus* sp.
  8. *Melanotus* sp. and *Agriotes mancus*
  9. Species recorded by Johnson 1927,  
pp. 100-102.
  10. *Ludius cylindriformis* Say.

Wireworms are important pests in all parts of Maine wherever agricultural crops are grown (see map. Fig. 1). They inhabit the farming areas of the coastal region bordering on the Atlantic Ocean. They are found in the farming districts of Central and Western Maine, and extend their depredations along the river valleys and across the uplands northward into Somerset and Piscataquis Counties. Wireworms are well scattered over Penobscot and Southern Aroostook Counties and are found locally even in certain Northern Aroostook County areas (Fig. 1). Wireworms are especially troublesome in Central Maine localities and sometimes become so destructive there that whole areas of growing crops are destroyed (Plate 1).

#### SPECIES OF WIREWORMS FOUND IN MAINE AS ADULT BEETLES

There are 51 known species of Elateridae, or wireworms as adults, inhabiting Maine (see following list of Maine Elateridae).

#### LIST OF MAINE ELATERIDAE (BEETLES)

##### ELATERIDAE

###### PYROPHORINAE

###### PYROPHORINI

###### Agrypnina

*Adelocera brevicornis* Lec. (Me. Agr. Exp. Sta. Lot 1617-261)

*Adelocera obtecta* Say (Me. Agr. Exp. Sta. Lot 1617-260)

###### Hemirhipina

*Alaus oculatus* Linn. (Me. Agr. Exp. Sta. Lot 1617-262)

##### PITYOBIINI

*Pityobius anginus* Lec. (Me. Agr. Exp. Sta. Lot 306)

##### LEPTUROIDINI

###### Athouina

*Limonius plebejus* Say (Me. Agr. Exp. Sta. Lot 2073)

*Limonius agonus* Say (Me. Agr. Exp. Sta. Lot 1914)

*Athous brightwelli* Kby.<sup>3</sup>

<sup>3</sup> Recorded from Maine by Johnson (1927).

## Lepturoidina

*Lepturoides denticornis* Kby.<sup>3</sup>

## Ludiina

*Ludius kendalli* Kby. (Me. Agr. Exp. Sta. Lot 2108)*Ludius vernalis* Hentz. (Me. Agr. Exp. Sta. Lot 2083)*Ludius resplendens* Esch. (*aurarius* Rand)<sup>4</sup>*Ludius sjællandicus* Müller (Me. Agr. Exp. Sta. Lot 2110)*Ludius cylindriformis* Hbst. (Me. Agr. Exp. Sta. Lot 2074 and others)*Ludius appressus* Rand.<sup>4</sup>*Ludius caricinus* Germ. (Me. Agr. Exp. Sta. Lot 2076)*Ludius tarsalis* Melsh. (Me. Agr. Exp. Sta. Lot 1617-29)*Ludius spinosus* Lec.<sup>3</sup>*Ludius insidiosus* Lec. (Me. Agr. Exp. Sta. Lot 2082)*Ludius hamatus* Say<sup>3</sup>*Ludius triundulatus* Rand. (Me. Agr. Exp. Sta. Lot 1617-279)*Ludius medianus* Germ.<sup>3</sup>*Ludius aereipennis* Kby. (Me. Agr. Exp. Sta. Lot 1617-20)*Ludius nigricornis* Panz.<sup>3</sup>*Ludius aratus* Lec.<sup>3</sup>*Ludius cruciatus* Linn. (Me. Agr. Exp. Sta. Lot 1617-31)*Ludius hieroglyphicus* Say (Me. Agr. Exp. Sta. Lot 1617-280)*Hemicrepidius decoloratus* Say (Me. Agr. Exp. Sta. Lot 2079)*Hemicrepidius memnonius* Hbst. (Me. Agr. Exp. Sta. Lot 2080)

## HYPNOIDINI

*Cryptohypnus abbreviatus* Say (Me. Agr. Exp. Sta. Lot 1617-265)*Hypnoidus tumescens* Lec. (Me. Agr. Exp. Sta. Lot 2114)<sup>4</sup> Recorded from Maine by Leng (1920).

## OESTODINI

*Oestodes tenuicollis* Rand. (Me. Agr. Exp. Sta. Lot 2113)

*Oestodes* sp. (Larva determined by Dr. A. G. Böving  
3/10/33.)

## ELATERINAE

## STEATODERINI

## Steatoderina

*Dolopius lateralis* Esch. (Me. Agr. Exp. Sta. Lot 1617-29 and 1616-141)

## AGRIOTINI

## Agriotina /

*Agriotes mancus* Say (Me. Agr. Exp. Sta. Lot 1617-38)

*Agriotes ferrugineipennis* Lec.<sup>3</sup>

*Agriotes pubescens* Melsh. (Me. Agr. Exp. Sta. Lot 1617-269, 270)

*Agriotes limosus* Lec.<sup>3</sup>

## Adrastina

*Betarmon bigeminatus* Rand. (Me. Agr. Exp. Sta. Lot 2111)

*Adrastina* sp. (Larval specimen, Me. Agr. Exp. Sta. Lot 1897)

## ELATERINI

## Elaterina

*Elater pullus* Germ.<sup>4</sup>

*Elater semicinctus* Rand.<sup>4</sup>

*Elater rubricus* Say<sup>3</sup>

*Elater apicatus* Say (Me. Agr. Exp. Sta. Lot 1617-266)

*Elater mixtus* Hbst.<sup>3</sup>

*Elater nigricans* Germ.<sup>3</sup>

## MELANOTINI

*Melanotus castanipes* Payk. (Me. Agr. Exp. Sta. Lot 1617-272)

*Melanotus leonardi* Lec. (Me. Agr. Exp. Sta. Lot 2109)

*Melanotus communis* Gyll. (Me. Agr. Exp. Sta. Lot 1617-273)

*Melanotus fissilis* Say (Me. Agr. Exp. Sta. Lot 1383)

*Melanotus pertinax* Say (Me. Agr. Exp. Sta. Lot 2077)

*Melanotus* sp. (Me. Agr. Exp. Sta. Lot 2078)

## CARDIOPHORINAE

*Cardiophorus gagates* Er. (Me. Agr. Exp. Sta. Lot 2112)

*Cardiophorus convexulus* Lec.

*Cardiophorus (dispar) filius* Rand.<sup>4</sup>

*Cardiophorus* sp. (Me. Agr. Exp. Sta. Lot 2081)

From the standpoint of abundance in Maine and injuries done to the crops of the State, the most important wireworms are the wheat wireworm, *Agriotes mancus*, followed in descending order by those of the genera *Melanotus*, *Ludius*, and *Limonius*.

A GENERAL DESCRIPTION OF THE ADULTS OF THE WHEAT  
WIREWORM, *Agriotes mancus* Say

John Curtis in his "Farm Insects" (1860, p. 153) says of the beetles of the family Elateridae: "These beetles have been called elaters from a peculiar power they have of leaping up like a tumbler when placed on their backs, and for this reason they have received the English appellations of 'spring beetles' and 'skip-jacks,' and from the noise which the apparatus makes when they leap they are also called 'snap' or 'click-beetles,' and likewise 'blacksmiths.'"

Elaterid beetles taken in Maine vary in length from about one-eighth of an inch to more than one inch in length. Their colors for the most part are somber tones of brown, grey, or black. A few are bicolored with the head and thorax reddish and the elytra and abdomen black or with the head and thorax shiny-black and the elytra and the abdomen brownish.

The larger beetles are commonly of the type known as the eyed elaters and are greyish in color with a pair of eye-like spots on the dorsum of the thorax. Elaterid beetles are often called "click-beetles" or "skipjacks" in Maine.

The springing motion of which beetles of the family Elateridae are capable when turned over on their backs, is possible because of certain structural characteristics. The prothorax and mesothorax are loosely joined (Fig. 2A and B), the base of the prothorax and the base of the elytra slope downward toward each other, and the prosternum is prolonged into a spine (Fig. 3A, S) which projects caudally to fit into the mesosternal cavity (Fig. 3B, C). Preparatory to springing into the air, the prothorax is bent

downward and the prosternal spine is drawn upward and forward out of the cavity. Then when the muscles are suddenly relaxed the prosternal spine descends, strikes against the cavity, and slips into place. At the same time the elastic base of the elytra striking against the surface upon which the beetle is resting causes the insect to be thrown into the air.

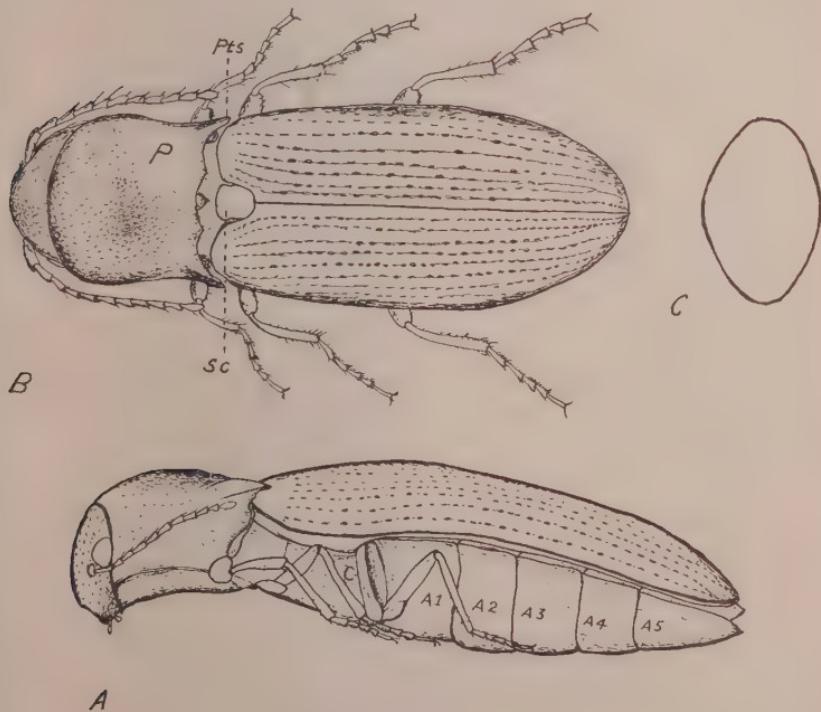


FIG. 2. A. Adult of *Agriotes mancus* Say. Lateral view  
A1 to A5 ventral abdominal segments

C. metathoracic coxa

B. Adult of *Agriotes mancus* Say. Dorsal view

P. prothorax

Pts. prothoracic spine

Sc. scutellum

C. cross section through adult of *Agriotes mancus* Say

### A DETAILED DESCRIPTION OF THE ADULTS OF THE WHEAT WIREWORM, *Agriotes mancus* Say

The parent beetles of the wheat wireworm, *Agriotes mancus* Say, were described by Thomas Say (1823). They are small elaterid beetles averaging approximately 8 mm. in length, 3 mm. in maximum width, and about 2 mm. in greatest depth (Plate 1B). The general body color is a dark chestnut-brown except when the beetles are newly formed; then they are yellowish or tan in color. The legs and antennae are yellowish and the entire body is clothed with a fine yellowish pubescence. The major body divisions of a beetle of this species is shown in Figure 2A and B. The general shape of the body is elongate oval in dorsal aspect and the caudo-lateral margins are produced to form the subacute caudal body termination (Fig. 2B). The lateral margins of the elytra are nearly parallel for a distance caudad to their base and they are then rounded posteriorly. The dorsal surface of the body is convex in form and the ventral surface is slightly flattened. A cross section taken near the center of the body is subovate in outline (Fig. 2C). The pubescence which clothes the body arises from minute pores in the exoskeleton (Fig. 3C). The legs, antennae, and mouth appendages are capable of retraction close against the body, and the entire body and all the appendages are heavily sclerotized.

The dorsocaudal margin of the head is ordinarily hidden beneath the cephalic margin of the prothorax, but it is revealed as arcuate in form when the head is separated from the thorax (Fig. 3D). No epicranial suture is present and the frons is not distinct from the epicranium. Two compound eyes (E) are located, one on either side of the head, at about half the dis-

FIG. 3. A. Prosternum of *Agriotes mancus* Say.

Sh.	prosternal shelf
CC.	coxal cavities
S.	spine

B. Mesosternum and metasternum of *Agriotes mancus* Say.

S2.	mesosternum
S3.	metasternum
C.	mesosternal cavity
Eps.	episternum
Epm.	epimeron
CC.	coxal cavity
Su.	metasternal suture
Ac.	anticoxal piece

C. Pubescence of adults of *Agriotes mancus* Say.

D. Head of *Agriotes mancus* Say. Cephalic view.

Ant.	antennae
E.	eye
Fr.	frontal ridge

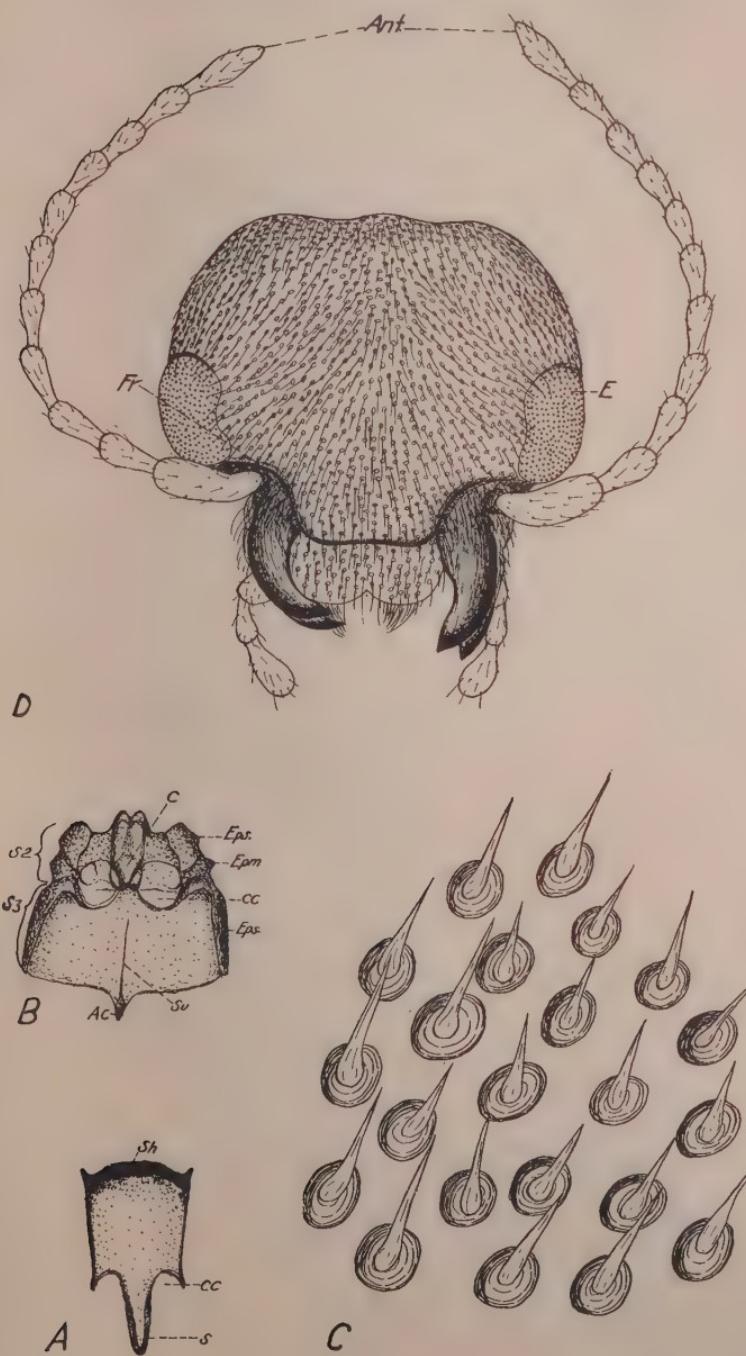


FIG. 3

FIG. 4. A. Lower mouthparts of *Agriotes mancus* Say.

Mp.	maxillary palpus
G.	galea
L.	lacina
S.	stipes
C.	cardo
Li.	ligula
Lp.	labial palpi
M.	mentum
Sm.	submentum
Gs.	genal suture
Pg.	palpiger

B. Mandible of *Agriotes mancus* Say.

Add.	adductor mandibulae
Br.	brustia
D.	dentes
Vc.	ventral condyle

C. Prothorax of *Agriotes mancus* Say. Dorsal view, slightly tipped to show lateral view of prosternum.

Ptd.	prothoracic disk or notum
Pts.	prothoracic spine
Lc.	lateral carina
Eps.	episternum
Epm.	epimeron
Pss.	prosternal spine
Pssu.	prosternal suture
CC.	coxal cavity

D. Prothoracic leg of *Agriotes mancus* Say.

C.	coxa
F.	femur
Tr.	trochanter
T.	tibia
Ta 1 to Ta 5.	tarsal segments
Tc.	tarsal claws

E. Elytrum of *Agriotes mancus* Say.

S.	stria
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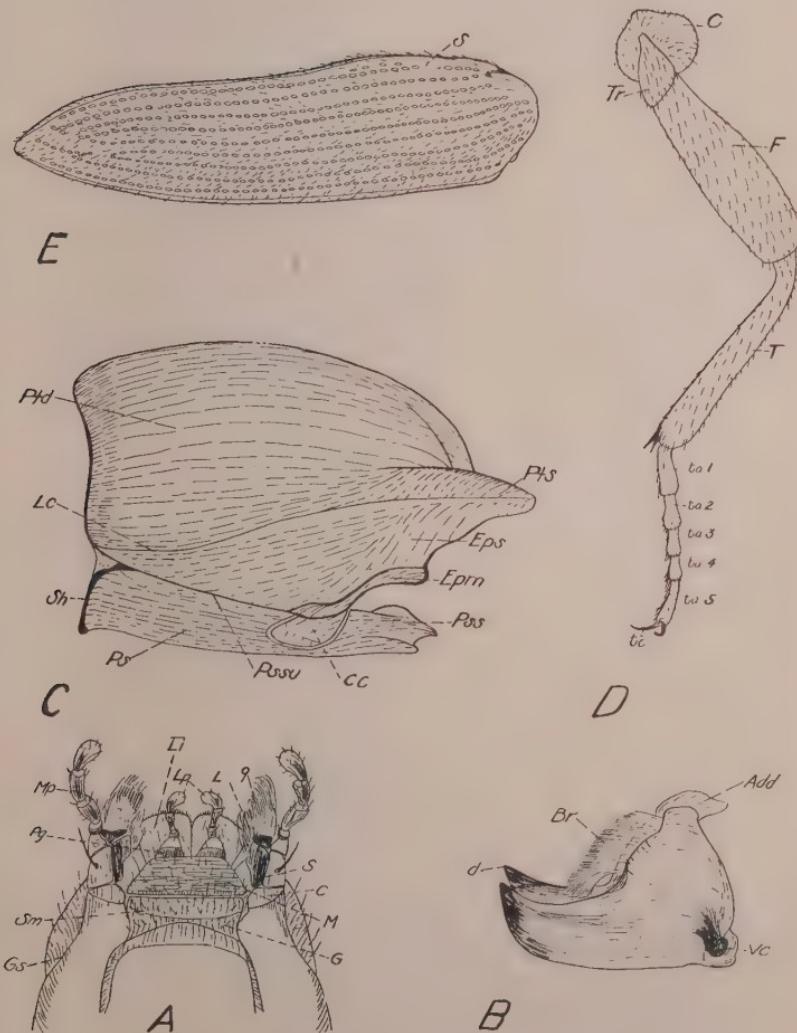


FIG. 4

tance between the dorsum and venter. The antennae are of the modified serrate type and consist of eleven joints (Ant). They arise from sockets which are located beneath frontal ridges. The frontal ridges extend from near the inner cephalic margins of the compound eyes to the lateral points of attachment of the labrum (Fr). The elbowed first antennal segment is somewhat larger than the other joints and the ball on its proximal end is received in the antennal socket or fossa. Joints two to ten are somewhat similar in form. They are cylindrical and slightly club-shaped. The eleventh segment is elongate-oval in general form and terminates distally in a somewhat blunt point. Fine short hairs are present on all the segments of the antennae.

The genae are limited caudally by a distinct suture (Fig. 4A, Gs). Post genal sclerites are separated from the epicranium by a scarcely discernible suture. Mandibles are broad at their proximal attachment to the head (Fig. 4B). They taper and curve toward the meson where they terminate as broad, curved hooks. They are cleft near the tip (d) and the left mandible closes over the right one. The exposed lateral surfaces of the mandibles are set with fine short pubescence on the dorsal surfaces of their basal portions and numerous hairs (Br) are present on the mesal margins.

The submentum (Fig. 4A, Sm) is attached to the distal margin of the gula (G) and maxillae are inserted on either side of the gula a short distance caudad to the attachment of the submentum. Numerous bristle-like hairs are present on the mesal and distal margins of both lacinae and galeae. The maxillary palpi (Fig. 4A, Mp) are four-jointed, the distal joint being flat, blade-like, and curved on its inner margin. Joint three is larger at its distal extremity than at the proximal attachment and is slightly elbowed. Joint two is cylindrical and club-shaped. The proximal joint is small and knuckle-like in form. A few short hairs are present on the maxillary palpi and are largest on the distal portions of the middle segments. The mentum (M) is a large transverse sclerite, and the submentum (Sm) is small and inconspicuous. The ligula is large, flat, and bilobed with numerous hairs on the distal margin (Li). The labial palpi (Lp) are three-jointed. The third joint is hatchet-shaped, the second joint is cylindrical and somewhat elbowed, and the first joint is smaller than the other two. A few fine hairs are present on the palpi.

The prothorax is the largest and most conspicuous of the thoracic segments (Fig. 2A and B). As seen in dorsal view, it is slightly wider than long and its sides curve outward from the cephalic margin, then inward and finally outward again toward the apex. There is a slight median depression present on the basal one-third of the dorsal portion of the prothorax sometimes called the prothoracic disk. Two truncate prolongations or prothoracic spines (Pts) embracing the base of the elytra are produced from the caudo-lateral angles of the prothoracic disk. These spines are margined dorsally and laterally by longitudinal carina, the lateral carina being the longer. The entire prothoracic disk is densely punctate and pubescent. It is limited in a ventrocephalic direction on each side by the continuation of the lateral carina (Fig. 4C, Lc). The episterna (Eps) are inflexed toward the prosternum (Ps) from which they are separated by trough-like prosternal sutures (Pssu).

The prosternum is the central sclerite on the ventral surface of the prothorax (Fig. 4C, Ps). It lies cephalad of the first pair of legs, except for the prosternal process or spine (Pss) which projects caudally between the legs and fits into a cavity in the mesothorax (Fig. 3B, C). On the ventral surface, the prosternum is convex and the cephalic margin is expanded to form a rim or shelf (Fig. 3A, Sh) which serves to protect certain sensitive portions of the head and cervical region (see also Fig. 4C). The laterocephalic angles of the prosternum are angular and project slightly in the direction of the head. The coxal cavities (Fig. 3A, CC) are separated from each other by the base of the prosternal process.

The coxal segment (C) of the prothoracic leg (Fig. 4D) is globular in form. The trochanter (Tr) is smaller than the coxa and is of a general triangular shape. The femur (F) is short and stout compared to the more slender tibia. The tibia (T) is slightly elbowed near its proximal end and a pair of tibial spurs is borne at its distal extremity. The tarsus (Ta 1-5) is five-segmented. Tarsal segments are larger at their distal than at their proximal extremities and they are clothed beneath with spongy pubescence. A pair of curved, simple, divergent claws (tc) are attached to the last segment. The outer surface of the entire leg is sparsely pubescent.

The convex elytra are borne on the dorsal surface of the mesothorax. Each elytron (Fig. 4E) is furrowed by nine longitudinal striae (S). Oval punctures occupy the troughs of the striae and fine setae cover the entire elytral surface (Fig. 5). The elytra meet in a straight line on the meson, are rounded at the proximal margin, and are somewhat expanded in the humeral region. The shield-shaped scutellum is located on the meson between the bases of the elytra (Fig. 2B, Sc).

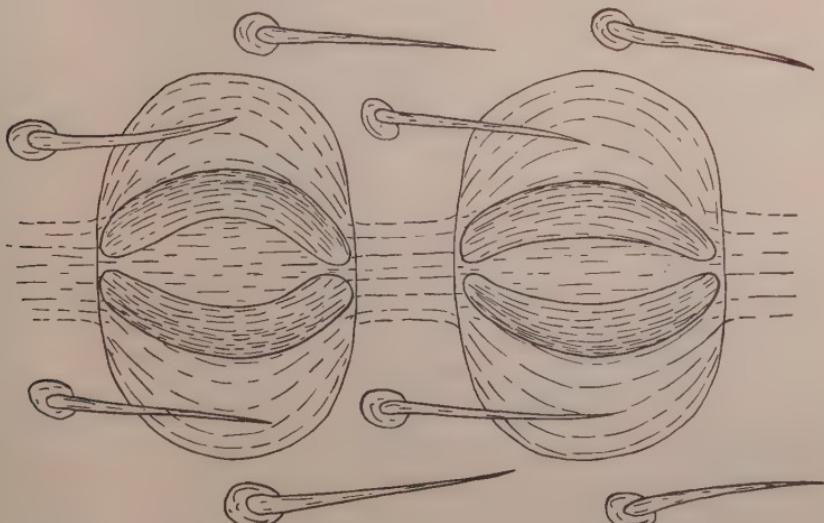


FIG. 5. Punctures and setae of elytra of *Agriotes mancus* Say.

- FIG. 6. A. Wing of *Agriotes mancus* Say. Showing veins and cross veins, cells and folds as typically occur.
- B. Wings of *Agriotes mancus* Say.
1. Right wing  
W. wedge cell
  2. Left wing  
L. longitudinal
- C. Wings of *Agriotes mancus* Say.
1. Right wing  
W. wedge cell  
T. transverse cell
  2. Left wing, showing different condition  
of anal region
- D. Wings of *Agriotes mancus* Say.
1. Right wing  
W. wedge cell L. longitudinal cell
  2. Left wing, showing condition in anal region
- E. Wings of *Agriotes mancus* Say.
1. Right wing  
W. wedge cell  
T. transverse cell
  2. Left wing showing absence of transverse cell  
between Sc and R1
- F. Wing of *Agriotes mancus* Say.  
T. transverse cell
- G. Wing of *Agriotes mancus* Say.  
W. wedge cell  
r. cross vein split to form a triangular cell
- H. Wing of *Agriotes mancus* Say.  
W. wedge cell
- I. Wing of *Agriotes mancus* Say.  
W. wedge cell
- J. Wing of *Agriotes mancus* Say.  
L. longitudinal cell
- K. Wing of *Agriotes mancus* Say.
- L. Wing of *Agriotes mancus* Say.
- M. Wing of *Agriotes mancus* Say.
- N. Wing of *Agriotes mancus* Say.
- O. Wing of *Agriotes mancus* Say.
- P. Wing of *Agriotes mancus* Say.
- 2dA2-2dA3. Cross vein connecting 2dA2 to 2dA3.

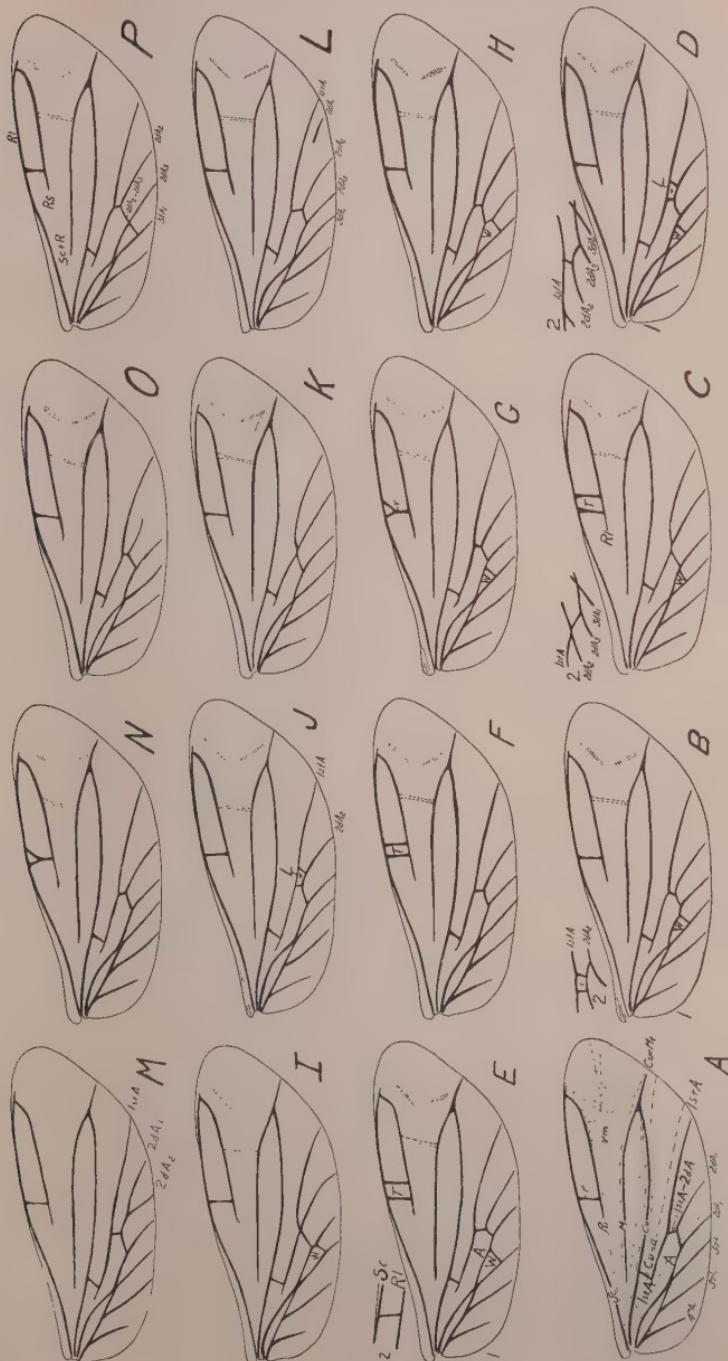


FIG. 6

The mesothorax is the smallest of the thoracic segments. It is covered dorsally by the elytra and but a small portion of it is to be seen when the legs are attached and the wings are in a resting position. The mesosternum (Fig. 3B, S2) contains a mesosternal cavity (C), into which fits the prosternal spine. The coxal cavities (CC) are located subventral to and a little caudad of the mesosternal cavity. The episternum (Eps) and the epimeron (Epm) are evident on the ventral surface of the mesothorax. The coxal cavities of the mesosternum are closed behind. The legs borne by the mesosternum are not significantly different from those of the prothorax except that the coxae are somewhat cone-shaped rather than globular in form.

The metasternum (Fig. 3B, S3) is that part of the metathorax most evident in ventral aspect. A median suture extends along the mid-ventral portion of the metasternum for about three-fifths of the distance from the caudal margin to the coxal cavities of the mesothorax. Coxae of the metathorax are partially separated by an angular portion of the metasternum, the anticoxal piece, which extends backward along the central meson separating the bases of the coxae for a distance of about one-half their width. Metasternal coxae (Fig. 2A, C) are expanded toward the midventer and partially cover the thighs.

Hind or metathoracic wings of this species are thin with numerous veins. They are entirely covered by the heavily sclerotized elytra when not expanded for flight. The tip is folded in two oblique folds in the apical region between the costal margin of the wing and the combined median and cubital veins ( $Cu$  and  $M_4$ ) and is then tucked beneath the wing so that the tip lies under the elytron. (See Fig. 6A, folds indicated by dotted lines.)<sup>5</sup> There is a longitudinal fold along radius, one between radius and media, one near cubitus, and one between media and cubitus. Between cubitus and the first anal vein, 1stA, there are two longitudinal folds, one near cubitus and one near 1stA. In the anal ergion there is one longitudinal fold extending through the anal cell (A) to the margin of the wing between vein second anal two (2dA2) and second anal three (2dA3). There is another longitudinal fold extending to the anal margin of the wing between 3dA2 and 4dA1 by which the anal lobe is narrowed. These foldings reduce the width of the hind wing so that it is no wider than the elytron.

There is considerable variation in the venation of the hind wings of *Agriotes mancus* Say. The type of venation most often found is indicated by Figure 6A which is used as a standard for comparison of other types. In this type of wing there are no closed cells in the anal region nearer to the margin than the large cell designated as A and the cross vein r is single. In the right wing (Fig. 6B, 1) a wedge cell (W) is present in the anal region below the anal cell. The wedge cell is absent in the left wing of the same beetle but a longitudinal cell (Fig. 6B, 2 L) is present in the region beyond the anal cell between 1stA and 2dA2. In the right wing (Fig. 6C, 1) a transverse cell (T) is present in addition to the wedge cell. Veins A1 and 2dA2 coalesce for a short distance near the anal cell and the wedge cell is

<sup>5</sup> Wing veins are lettered after Forbes (1922 Pl. XXXII, Figs. 30, 31).

somewhat smaller and is slightly farther from the anal margin than is the case of the wedge cell in Figure 6A. In the left wing (Fig. 6C, 2) both the wedge cell and the transverse cell are absent; otherwise the left wing is similar to the right wing. The right wing (Fig. 6D, 1) has both a wedge cell and a longitudinal cell (L). In the left wing both these cells are absent (Fig. 6D, 2). In the right wing (Fig. 6E, 1) the condition is the same as in Figure C except that 1stA and 2dA2 are separate beyond cell A. In the left wing the condition is the same as in the right except that there is no transverse cell (Fig. 6E, 2). The right wing (Fig. 6F) contains a transverse cell between R1 and Rs while the left wing is the standard type (Fig. 6A) as is the left wing in all the rest of the wings subsequently described. The cross vein (r) in the right wing (Fig. 6G) is split so that the cell is triangular instead of transverse as in Figure 6F. The presence of a wedge cell in the right wing (Fig. 6H) differentiates it from the standard type. However, the cell is slightly different from the ordinary wedge type in that it is somewhat trapezoidal in shape. The wedge cell in the right wing (Fig. 6I) is set closer to the margin of the wing and is narrower and longer than the wedge cell in Figure 6H. A longitudinal cell (Fig. 6J, L) is present in the anal region distad of the anal cell between 1stA and 2dA2. This wing is similar to the one shown in Figure 6D, 1 except for the absence of the wedge cell. The right wing (Fig. 6K) is like the standard type (Fig. 6A) except that 1stA and 2dA2 coalesce for a short distance distad of the anal cell. The right wing (Fig. 6L) has a trace of vein between 1stA and 2dA2 which is probably 2dA1. The vein 2dA1 is two-branched (Fig. 6M). The right wing illustrated in Figure N is similar to Figure 6G but lacks the wedge cell present in the latter. The wing illustrated in Figure 6O is similar to the standard type (Fig. 6A) except that none of the veins in the anal area attain the margin. The right wing represented in Figure 6P differs from all others examined in having the cross vein 2dA2—2dA3 extending in a straight line with the cross vein 2dA3—3dA1. This forms the short side of the wedge cell of a different type as compared with those in other wings of this species examined.

There are five ventral non-protrusible abdominal segments discernible in beetles of *Agriotes mancus* Say (Fig. 2A, A1 to A5). The proximal segment is narrowed by the expanded coxae of the metathoracic legs. Only the fifth is capable of free movement. There are seven non-protrusible segments on the dorsum of beetles of this species (Fig. 7, a and d, 1 to 7). Each of these segments bears a pair of spiracles (Sp 1 to 7). The spiracles of the proximal segment are larger than any of those of the posterior segments.

The protrusible segments of the female (Fig. 7A, b) consist of the eighth and ninth abdominal segments if the sheath of the ovipositor (Sh) is considered as a segment. The eighth, ninth, and tenth abdominal segments of the male are protrusible. An apparent pair of spiracles is barely discernible on the lateral margins of the eighth segment of the female (a, Sp 8). A like pair is also present on the lateral margins of the eighth abdominal segment of the male but cannot be seen in dorsal view. The difference in

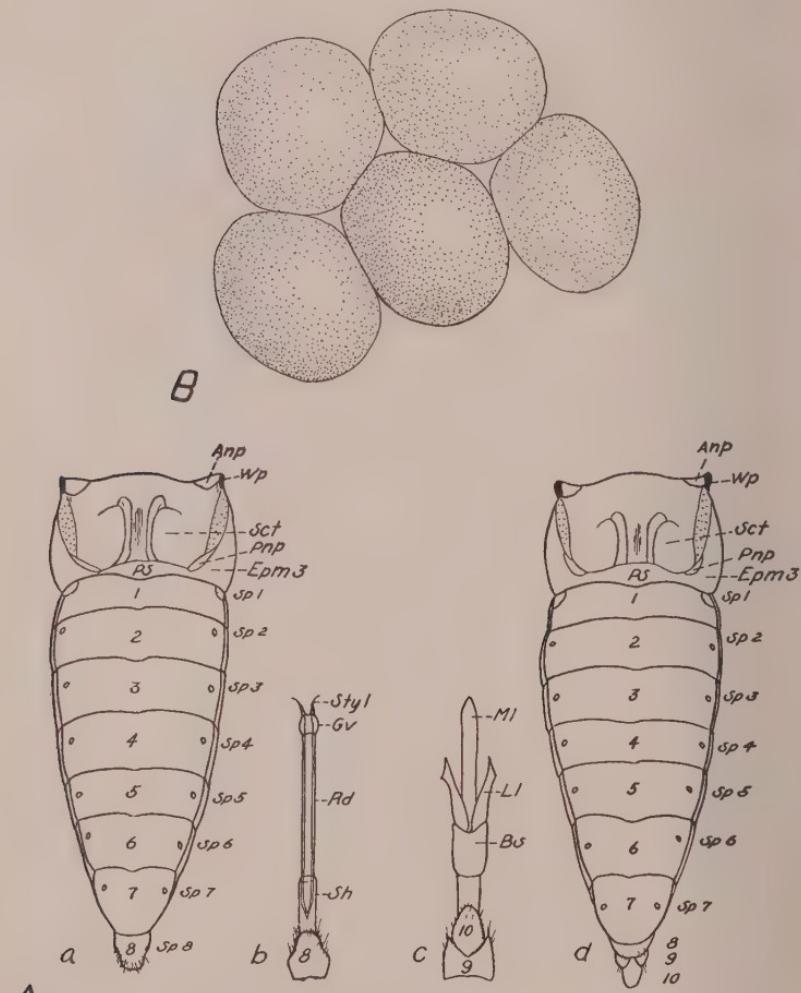


FIG. 7. A. *Agriotes mancus* Say.

(a) dorsal view of female segments ordinarily covered by elytra.

Anp, anterior notal process, Wp, wing process, Sct, scutellum, Pnp, posterior notal process, Epm3, epimeron of the metathorax, P.S. post scutellum, Sp 1 to 8, spiracles 1 to 8 abdominal segments.

(b) protrusible abdominal segments of female.

Styl, styllets, Gv, genital valve, Sh, sheath, Rd, rod.

(c) protrusible abdominal segments of male.

Ml, middle lobe, Ll, lateral lobe, Bs, basal segment, 10, tenth segment, 9, ninth segment.

(d) dorsal view of male segments ordinarily covered by elytra (Legend same as under (a).)

B. Eggs of *Agriotes mancus* Say.

size as encountered among the beetles is not a sexual character that can be relied upon, and no external characters are evident by which the sexes can be identified. Therefore, knowledge of the genitalia of *Agriotes mancus* is necessary in order that the sexes can be separated.

#### THE EGGS OF THE WHEAT WIREWORM, *Agriotes mancus* Say

Newly laid eggs of *Agriotes mancus* Say are white and glossy. In the light they glisten like tiny pearls (Plate II, A and B). Measurements of several eggs reveal their average approximate diameter as 548 microns longitudinally and as 442 microns transversely. Many of the eggs are oval in form, although some are almost spherical and a few are irregular in shape. Their small size and the fact that particles of earth and debris adhere to the eggs, obscure them in their soil environment. The egg shells are thin, elastic, and tough. When the shells are ruptured the liquid content of the eggs is exposed as a thick, creamy liquid. Although the liquid is an opaque fluid, the egg shells are transparent. The eggs take on a yellowish cast as they become older and the dark outline of the developing embryo can be seen inside. The nature of their physical surroundings apparently affects their form, for when they are laid in groups they are flattened at their points of contact with each other (Fig. 7B) and soil particles sometimes indent the surfaces of individual eggs. They adhere to each other when laid in groups because they are covered with a kind of varnish which quickly sets. When the varnish is dry the eggs do not have this adhesive quality.

#### THE LARVAE OF THE WHEAT WIREWORM, *Agriotes mancus* Say

The wheat wireworm, or larva of *Agriotes mancus* Say, is elongate and subcylindrical in form (Fig. 8A). The newly hatched wireworms of this species are very small when first hatched, being only about 1.8 millimeters in length. They are so small that they are seldom seen in the soil unless especial effort is made to find them. They are similar in form to the older larvae. The breadth of the body as seen in dorsal aspect is somewhat greater than the depth as seen in lateral aspect. This is due to the venter being slightly flattened. Many mature larvae attain a length of approxi-

mately 23 millimeters, or about an inch, and a breadth of about 1.6 millimeters, although some of them are smaller. The color of newly hatched and newly molted larvae is glistening white but approaches a bright yellowish-brown as the sclerotized areas harden and the larvae become older.

FIG. 8. A. The wheat wireworm, *Agriotes mancus* Say.

lm. lower mouthparts 1 to 13 body segments  
cv. conjunctiva

B. The wheat wireworm, *Agriotes mancus* Say. Ventral view of the ninth and tenth abdominal segments.

A9. ninth abdominal segment  
A10. tenth abdominal segment  
Pa. anal proleg  
a. anus  
Cv. conjunctiva

C. The wheat wireworm, *Agriotes mancus* Say. Lateral view of the ninth and tenth abdominal segment.

A9. ninth abdominal segment  
A10. tenth abdominal segment  
Cv. conjunctiva  
Pa. anal proleg  
I. invagination

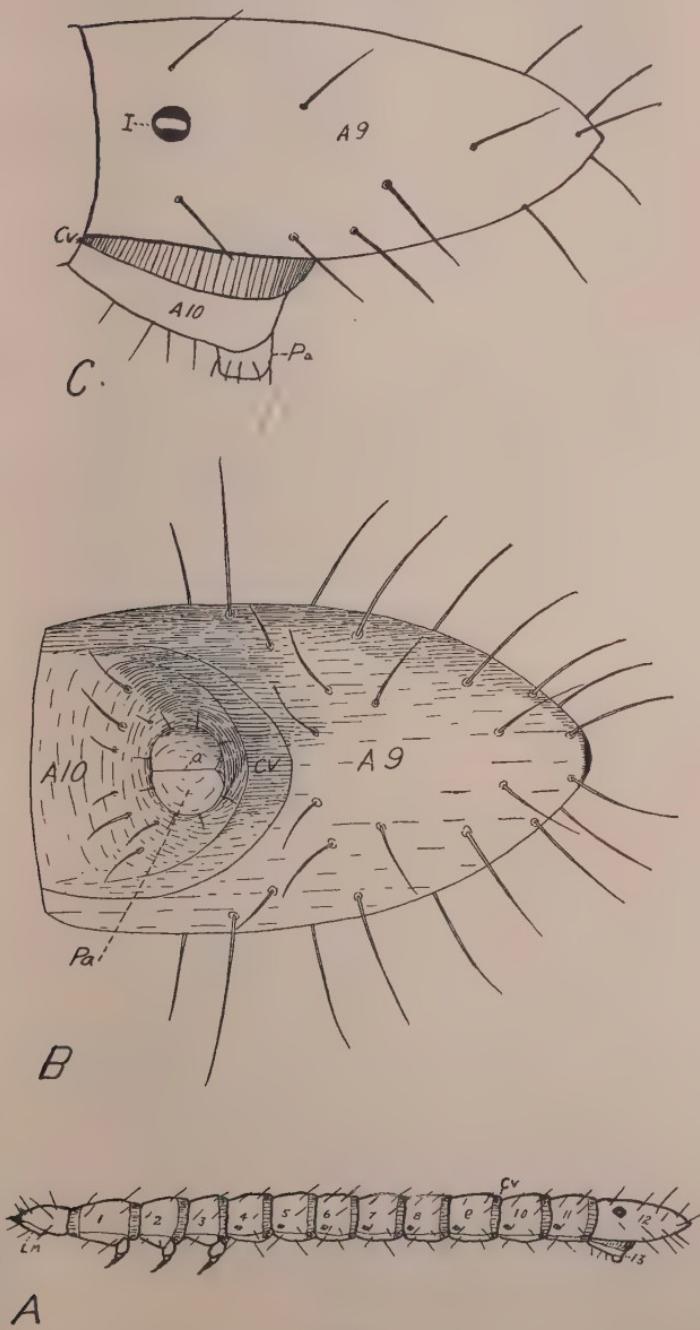


FIG. 8

DETAILED DESCRIPTION OF THE WHEAT WIREWORM, *Agriotes mancus* Say

The head, three thoracic, and ten abdominal segments, compose the body of the larvae of *Agriotes mancus* (Fig. 8A). Such external portions of the insect as are most often exposed are protected by the armor-like sclerotized exoskeleton. Some of the sclerites and all the segments are connected by elastic membranes or conjunctiva (Cv). These pliable connections permit

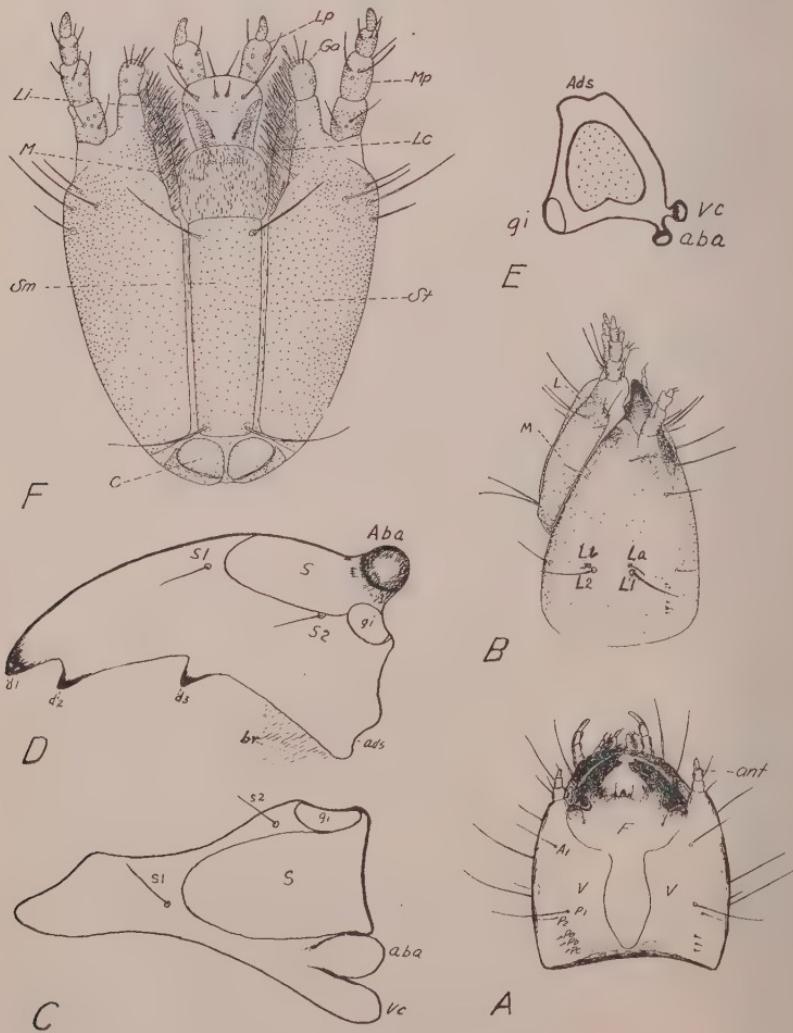


FIG. 9

FIG. 9. A. The wheat wireworm, *Agriotes mancus* Say. Dorsal view of head.

- Ant. antenna  
F. frons  
V. vertex  
A1. anterior seta  
P1. posterior seta  
P2. secondary posterior setae  
Pa. Pb. Pc. secondary posterior sensory pegs

B. The wheat wireworm, *Agriotes mancus* Say. Lateral view of the head.

- L1 and L2. lateral setae  
La and Lb. secondary lateral setae  
M. maxilla  
L. labium

C. Lateral view of the mandible of the wheat wireworm.

- S1 and S2. mandibular setae  
Gi. Ginglymus  
S. antennal scrobe  
Aba. abductor apodeme  
Vc. ventral condyle

D. Dorsal view of the mandible of the wheat wireworm

- Aba. abductor apodeme  
S. antennal scrobe or groove  
Gi. ginglymus  
Ads. depression where adductor mandibulae  
is attached  
d1. d2. d3. dentes

E. Proximal view of the mandible of the wheat wireworm.

- Ads. socket for attachment of adductor  
mandibulae  
Gi. ginglymus  
Vc. ventral condyle  
Aba. abductor apodeme

F. Maxillae and labium of the wheat wireworm.

- C. cardo  
St. stipes  
Sm. submentum  
M. mentum  
Li. ligula  
Lp. labial palpi  
Ga. galea  
Mp. maxillary palpus  
Lc. lacina

movement of the parts on each other and allow for flexibility of the larval body. The head is slightly narrower than the middle body segments. The body tapers from the abdomen toward the head and is terminated by the blunt cone-like ninth abdominal segment. The tenth abdominal segment is located ventrad to the ninth segment (Fig. 8B and C, A9 and A10). It is small, semioval in general form, and bears a single anal proleg on its midventral surface. A pair of legs is borne on each of the three thoracic segments and they with the anal proleg provide the only locomotory organs of larvae of *Agriotes mancus* Say.

The head of the wheat wireworm (Fig. 9A) is somewhat convex on its dorsal, lateral, and ventral surfaces. Its greatest length is almost twice its greatest depth and it is not quite as wide as it is long. The main part of the head is somewhat triangular in lateral aspect (Fig. 9B). Maxillae and labium (Fig. 9B, M and L) are appended to the head in such a manner that they jut forward giving the insect a prognathous appearance. The lateral margins of the head as seen in dorsal aspect are slightly convex and the head is broadest at about half the distance from the attachment of the mandibles to the dorsocaudal margin of the head (Fig. 9A).

The mandibles are broad and roughly triangular in dorsal and lateral aspect (Fig. 9C and D). They are sharp distally, curve toward the meson, are bidentate on their inner surfaces (Fig. 9D, d2 and d3) and are approximately trapezoidal in proximal view (Fig. 9E). The ginglymus of the mandible (Fig. 9C, D, and E, Gi) receives the dorsal condyle of the epipharynx and together they serve as a ball and socket joint for the dorsal articulation of the mandible to the head. The ball-like ventral condyle (Vc) of the mandible and its socket on the ventral part of the head serve as the ventral hinge and attachment of the mandible to the head. The adductor mandibulae is attached in a shallow socket (Ads) at the inner angle of the base of the mandible, and when the muscle contracts, the tips of the mandible are drawn toward the meson. The adductor muscle is strongly developed. The adductor mandibulae is attached to the knob-like abductor apodeme (Aba), which is located near the ventrolateral angle of the mandible at its junction with the head and when the muscles contract the tips of the mandible are forced outward from the meson. Thus, opening of the mandibles is accomplished by the abductor muscles contracting and pulling them apart. A pair of setae (S1 and S2) is present on the lateral surface of each mandible. Inner portions of the proximal antennal segments lie in grooves in the lateral surfaces of the bases of the mandibles (S).

The maxillae and labium (Fig. 9B, M and L) are inserted in a sinus in the ventral surface of the head, the point of insertion of their bases being some distance ventrocaudad to the articulation of the mandibles. The maxillae (Fig. 9F) lie beneath the mandibles and extend a little cephalad of them. Entire mesal and distal margins of the lacinae (Lc) are clothed with short bristly hair. The galea (Ga) is two-jointed and contains round pit-like sensory pores and several setae on the distal portion of the last segment. The maxillary palpi (Mp) are four-segmented, the fourth segment being cone-shaped and set with sensory pores at its tip. First and

second segments of the maxillary palpi contain round pits in their surfaces and setae are present on the first three segments. A set of four setae is present on the laterocephalic margin of each stipes. Cardines are also present (C). The labium, as seen in its ventral aspect, has the following parts: the submentum (Sm), the mentum (M), the ligula (Li), and the labial palpi (Lp).

Antennae are located one on each side of the epicranium near the base of the mandibles (Fig. 9A, Ant). They are three-jointed (Fig. 10A, 1, 2, 3) and are progressively smaller from the proximal to the distal segment. The small third segment and a cone-shaped papilla (P) are borne on the distal extremity of the second segment. A long seta and several shorter spine-like processes are located on the cephalic end of the third segment.

The fore part of the fronto-clypeal region is fused into a single piece in the larvae of *Agriotes mancus* to form the so-called nasale (Fig. 10B, Na). The nasale is trident in form when intact. When the dentes of the nasale are worn down or are broken they are sometimes smooth or nearly so. They are also sometimes worn round or they may be so broken that the nasale is monodentate or bidentate. Three pairs of setae are present on the frons and nasale.

The vertex of the epicranium (Fig. 9A, V) is somewhat convex as a whole but is slightly flattened cephalically. This flattening becomes more pronounced in the frontal region toward the nasale. Three pairs of very short posterior peg-like setae (Pa, Pb, Pc) are present on the caudal part of the vertex. A pair of long setae (P1) and a pair of shorter setae (P2) are located a short distance anterior to the shorter posterior group. A pair of anterior setae (A1) is located on the cephalic part of the vertex. There are two pairs of long lateral setae (Fig. 9B, L1 and L2). A short seta (La) is situated near the base of seta L1 and ventrad to it. There is also a short seta (L2a) near the long seta (L2). On the ventral surface of the epicranium there are two pairs of setae (Fig. 10C, V1 and V2). In addition to these there are the setae of the lower appended mouthparts which are shown in Figure 9F.

The prothorax (Fig. 10D) is somewhat of a truncated cone in general form. The circumference at the junction with the mesothorax is considerably greater than its circumference at the cephalic margin adjoining the head. An irregularity in the form of a ventral extending portion of the prosternum (S) is present at about two-thirds the distance from the cephalic to the caudal margin of the prosternum. The prothoracic tergum (T) covers the entire dorsal surface of the segment and extends ventrad on each side to the pleural sclerites (P). Spiracles are entirely lacking on the prothorax. A circular anterior band of flexible membrane, the conjunctiva (Cv1), connects the head to the thorax and permits the retraction of the posterior part of the head beneath the cephalic portion of the prothorax. A similar conjunctiva (Cv2) encircles the prothorax at the caudal margin. The cephalic part of the mesothorax is capable of being telescoped inside of this conjunctiva. The setal pattern of the prothorax varies somewhat from that of the other thoracic segments (Fig. DE) and from that of the abdominal segments (Fig. 10F).

FIG. 10. A. Antenna of the wheat wireworm.

1, 2, and 3. antennal segments  
P. cone-shaped papilla

B. The frons of the wheat wireworm, *Agriotes mancus* Say.

F. the main part of the frons  
Na. nasale

C. The ventral portion of the head of the wheat

wireworm, *Agriotes mancus* Say, minus the lower  
mouthparts.

V1 and V2 setae in the ventral surface of the  
vertex

D. The prothorax of the wheat wireworm, *Agriotes mancus*  
Say in the lateral view.

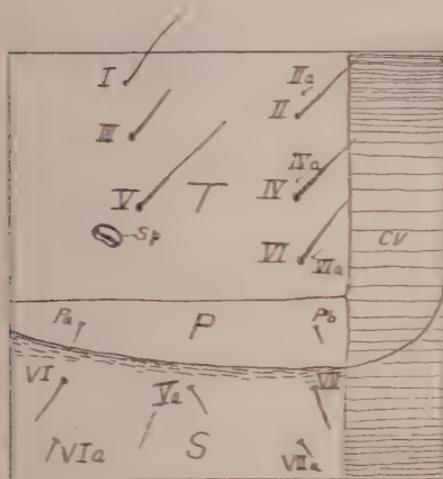
CV1 and CV2. conjunctivae  
T. prothoracic tergum  
P. prothoracic pleura  
S. prosternum

E. The mesothorax of the wheat wireworm, *Agriotes mancus*  
Say in the lateral view.

CV. conjunctiva  
Pi. peritrene  
Sp. spiracle  
T. tergum

F. A typical abdominal segment of the wheat wireworm,  
*Agriotes mancus* Say in the lateral view.

CV. conjunctiva  
T. tergum  
P. pleura  
IIa, IVa, VIa. secondary dorsal setae  
Pa and Pb. secondary setae of the pleura  
V I and V II. primary ventral setae  
Va, V Ia, and V IIa. secondary ventral setae  
I, II, III, IV, V, and VI. primary setae of tergum



F

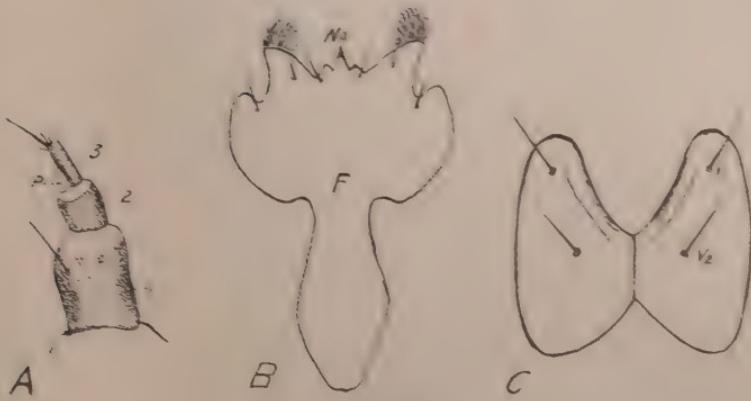
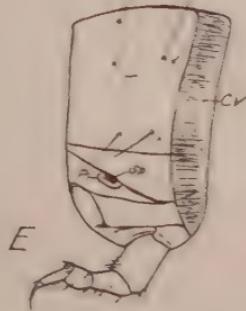
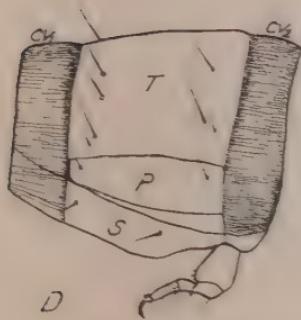


FIG. 10

The mesothorax (Fig. 10E) is shorter than the prothorax and is approximately cylindrical in form except for irregularities on the ventral portion. It is the only thoracic segment which bears spiracles. They are set in small indistinct oval sclerites of the pleura called peritremes (Pi). The setal pattern of the mesothorax differs somewhat from both that of the prothorax and that of the abdominal segments. The conjunctiva (Cv) is a flexible ring joining the mesothorax to the abdomen. Because of the flexible conjunctiva it is possible for the larvae of *Agriotes mancus* to partially telescope the body segments by forcing each of them forward inside the caudal part of a succeeding segment. The metathorax is similar in form, size, and setal arrangement to the mesothorax. However, the metathorax is slightly larger than the mesothorax.

A pair of legs similar to the one shown in Figure 11 is borne on the sterna of each of the thoracic segments. The thoracic leg is attached to the body dorsally by means of the pleural coxal process (Cpx). The subcoxal membrane (Scx) permits a flexible junction of the leg with the body. The coxa (C) is the largest of the leg segments. It is somewhat cylindrical in form, and is slightly concave on its dorsal surface. It is set with short spine-like setae in the lateral and ventral areas. The trochanter (Tr) is articulated to the coxa at two points, a and b. The femur (F) is short and stout, and the tibio-tarsus (TT) is comparatively long and tapering. The single-clawed tarsungulus (Tu) is attached to the distal extremity of the tibio-tarsus.

The larval abdomen of *Agriotes mancus* Say (Fig. 8A) consists of ten segments (4 to 13). Segments one to eight are similar in size and form. Flexible membranous rings or conjunctivae (Cv) connect all the segments transversely. The typical abdominal segment (Fig. 10F) consists of three main parts, the tergum (T), the pleuron (P), and the sternum (S). A longitudinal flexible membrane connects the pleura and sternum and allows considerable expansion and contraction between these sclerites. Each of the first eight segments of the abdomen bears a biforous spiracle (Sp) on either side just dorsad to the suture between the dorsum and pleuron and a little cephalad of the center of the dorsal sclerite. The setal pattern for the eight anterior segments is similar (Fig. 10F).<sup>6</sup> The ninth abdominal segment (Fig. 8B and C and Fig. 12A) is conoidal in form. It is this segment which forms the acute caudal apex of the body. The ninth segment is without apparent division between the dorsum and the pleura. An eye-like invagination (Fig. 8C and Fig. 12A) is located subdorsally on either side of the segment not far distant from the cephalic margin. The conjunctiva of the eighth segment permits telescoping of the cephalic portion of the ninth segment within its membranous fold. Setae of the ninth segment are numerous, especially toward the caudal extremity of the body.

The tenth abdominal segment (Fig. 8B and C, A 10) is much smaller than other body segments. It is attached to the ventral surface of the ninth

<sup>6</sup> Setae are numbered merely as a convenience without reference to homology.

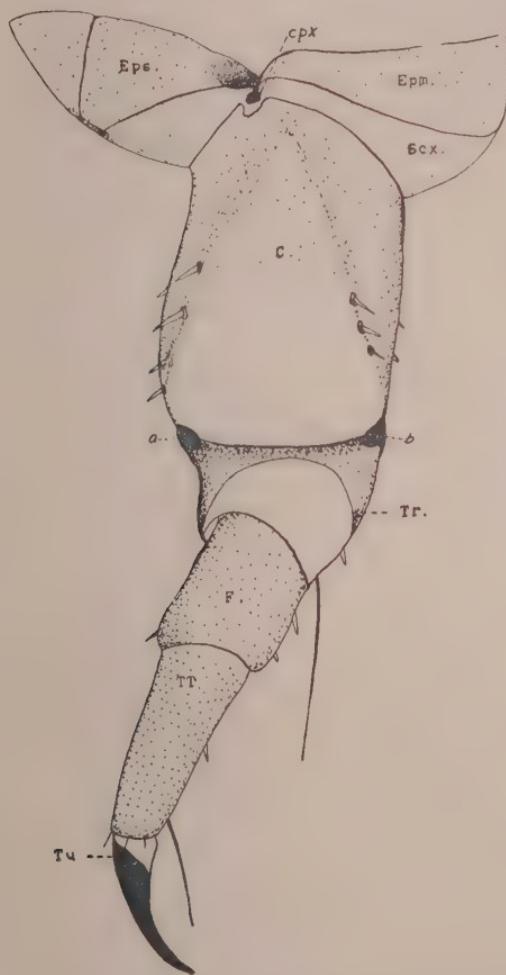


FIG. 11. Leg of the wheat wireworm, *Agriotes mancus* Say.

- Cpx. pleural coxal process
- Eps. episternum
- Epm. epimeron
- Scx. subcoxal membrane
- C. coxa
- A. articulations of the coxa and trochanter
- Tr. trochanter
- F. femur
- TT. tibio-tarsus
- Tu. tarsungulus

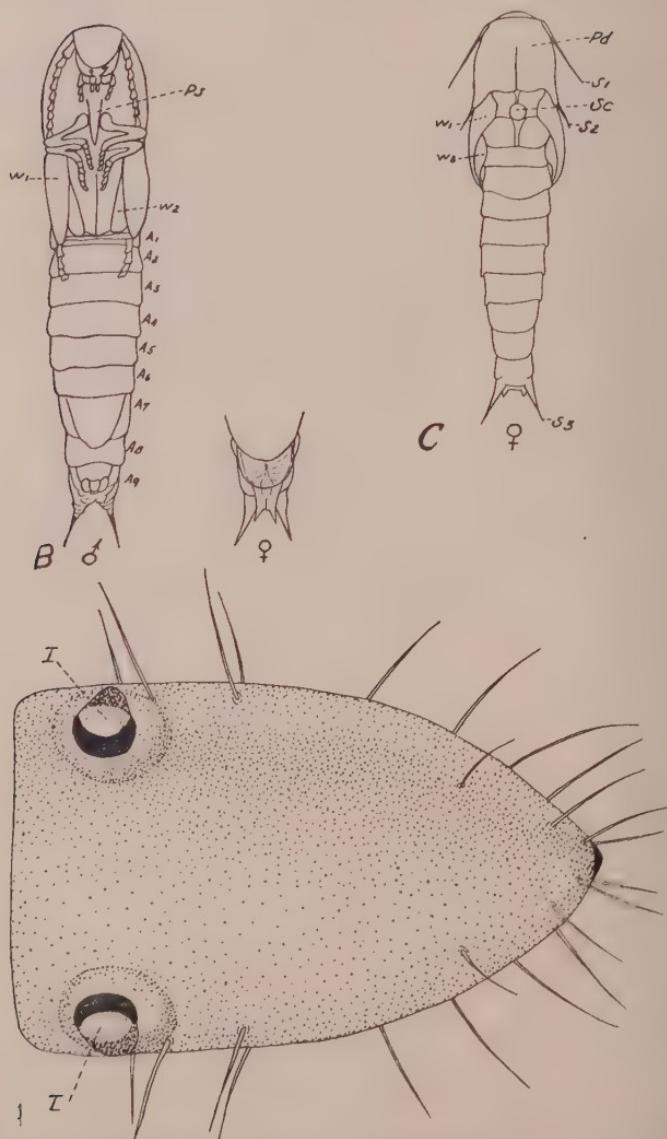


FIG. 12. A. Ninth abdominal segment of larva of *Agriotes mancus* Say.  
 I. eye-like dorsal invagination  
 B. ♂ Ventral view of male pupae of *Agriotes mancus* Say.  
 Ps. prothoracic spine, W1. elytron, W2. hind wing. A1 to  
 A9 abdominal segments  
 ♀ Ventral view of the tip of the female pupa of *Agriotes  
 mancus* Say.  
 C. Dorsal view of pupa of *Agriotes mancus*.  
 Pd. prothoracic disk, S1, S2, S3. spines, Sc. scutellum, W1  
 and W2. wings

segment by means of a flexible conjunctiva (*Cv*) and can be retracted somewhat beneath the folds of the conjunctiva and the surrounding edges of the ninth abdominal segment. The tenth abdominal segment is semioval in form in its ventral aspect (Fig. 8B). Setal patterns of this segment are variable in individual specimens of this species. They are usually, but not always, bilateral in their arrangement. The semiglobular, anal proleg (*Pa*) is borne on the ventrum of the tenth abdominal segment and the slit-like anal opening (*a*) is present in the ventral surface of the proleg. A circle of eight short, curved setae surround the ventral portion of the anal proleg.

#### THE PUPAE OF THE WHEAT WIREWORM, *Agriotes mancus* Say

Pupae of *Agriotes mancus* Say are shiny white in color. Their lustrousness gives them the appearance of having been modeled from some waxy substance. They are a little larger than the adults, being about 10 mm. in length and a little less than 3 mm. in width. There is some variation in size, however, which is to be expected in view of the fact that the adults also vary.

#### DETAILED DESCRIPTION OF THE PUPAE OF THE WHEAT WIREWORM, *Agriotes mancus* Say

External characters of the pupae correspond very closely to those of the adults, although the pupal appendages are not so well developed on the whole. In addition to the external characters usually found on the adults of this species, features of the genitalia are to be found on the ventral surface of the caudal segment of the abdomen (Fig. 12B, ♀ and ♂). A long spine is present at each of the two laterocephalic angles of the prothoracic disk as well as at the caudolateral angles of the same tergite (Fig. 12C, S1 and S2), and a pair of spines is present on the tip of the abdomen (S3). The prosternal spine (Fig. 12B, Ps) extends in a caudal direction between the bases of the prothoracic legs. A small portion of the head, the prothoracic disk, the scutellum (Fig. 12C, Sc), the mesothoracic wings (W1), the metathoracic wings (W2) and the tergites of nine abdominal segments are visible on the dorsal aspect of these pupae. The contrasting white of the pupae is very apparent when they are placed on a dark background (Plate II C) and because they are so white they are easily seen when broken out of their pupal cells in the soil.

#### THE LIFE HISTORY OF THE WHEAT WIREWORM, *Agriotes mancus* Say

Adults of *Agriotes mancus* Say occur in the soil as fully developed beetles within the pupal cells from August 5 to October 26 (Table 3). They have not

TABLE 3  
*Adult Occurrence of Agriotes mancus Say*

Year	Month	Day	Environment
1926	Aug.	5	Soil
1926	"	9	"
1926	"	19	"
1926	"	20	"
1926	Sept.	8	"
1926	Oct.	26	"
1927	Apr.	3	Under stones
1927	"	4	" "
1927	"	17	" "
1927	May	10	Crawling on soil
1927	June	15	Flight*
1927	"	24	"
1928	May	5	"
1928	"	8	Crawling on surface
1928	June	4	At clover baits
1928	"	8	" "
1928	Aug.	6	Soil
1928	"	12	"
1928	"	14	"
1928	"	28	"
1928	Sept.	16	"
1929	June	13	At clover baits
1929	"	20	" " "
1929	Aug.	17	Soil
1929	Sept.	15	"
1930	June	13	At clover baits
1930	Aug.	6	Soil
1930	"	28	"
1930	Sept.	10	"
1930	"	17	"
1931	June	6	Moving on soil and at clover baits
1931	"	13	At clover baits and in flight*
1931	"	15	At clover baits
1931	"	18	" " "
1931	"	24	" " "
1931	Aug.	9	Soil
1931	"	22	"
1931	Sept.	20	"
1931	"	27	"
1932	June	5	At clover baits
1932	"	8	" " "
1932	"	12	At clover baits and in flight*
1932	"	13	At clover baits
1932	"	15	" " "
1932	"	17	" " "
1932	Sept.	7	Soil
1932	"	19	"
1933	Aug.	7	"
1933	"	17	"
1933	Sept.	7	"
1933	"	11	"
1933	"	12	"
1933	"	13	"
1934	Apr.	24	"
1934	May	2	Beneath stones and moving on surface among debris of grassland
1934	"	2	Shaken from sods dug up
1934	June	7	Clover baits and in flight*
1934	"	8	Clover baits
1934	"	9	Clover baits and in flight*
1934	"	11	Clover baits
1934	"	12	Clover baits and in soil
1934	"	14	Mating
1934	"	18	Clover baits
1934	"	20	Clover baits and in flight*
1934	"	21	Mating
1934	"	23	Clover baits
1934	"	24	Mating in soil
1934	"	25	Clover baits

\* Caught on sticky shield while in flight.

been found within the pupal cells later than October 26 nor during the early spring months. They have been taken on a few occasions from beneath stones during April and May. Soil samples, taken during the winter from fields where the beetles are abundant during other seasons, have failed to disclose any beetles of this species. Their winter habitat in Maine is somewhat problematical. Comstock and Slingerland (1892, p. 256) report that in New York they spend the winter in the soil within the pupal cells. Hyslop (1916, p. 4) is also of the opinion that they remain over winter in the soil.

Movement of these beetles on the surface occurs during early spring only on warm days when the sun is shining and there is little wind blowing. May 4, 1934, was the earliest date on which the beetles were observed to move. The movement occurred about midday when the temperature reached a maximum of 74° F., and after the sun had been shining for several hours. No movement was observed to occur on the next day when the maximum temperature was 61° F. and the sun shone only intermittently.

Flight by beetles of *Agriotes mancus* Say occurs under approximately the same conditions as those required for surface movement. Occasionally a beetle will climb upon some object lying upon the surface and take wing in flight. The earliest flight record for this species is that of May 5, 1928, when a beetle flew against a sticky surface erected as a trap and was caught.

Beetles of this species run about on the surface of the soil during May and June. They enter cracks and crevices in the soil and crawl under stones and surface debris. A beetle may explore several such places before it remains hidden. Beetles followed and removed from their hidden retreats have been found to be associated with several other beetles. An examination of the beetles congregated shows that usually several males are associated with one or two females. The places of concealment are usually small cavities not more than an inch below the surface of the soil and are sometimes beneath a clod or stone. Mating takes place in these cavities and occasionally eggs are laid there also.

TABLE 4

*Clover Baits for Elaterid Beetles*  
*Agriotes mancus* Say  
June, 1934

Day of the Month	Number taken
7	13
8	248
9	86
11	537
12	186
14	56
16	183
18	418
21	204
23	170
25	28

Mating by beetles of *Agriotes mancus* Say occurs in nature, according to our observations, as early as June 12, although it probably occurs even earlier, inasmuch as gravid beetles have been taken by June 10 which later laid fertile eggs. The number of eggs laid by a single beetle varies considerably with the individual. The largest number of eggs obtained from a single female was 60 and the smallest number was 2 (Table 7).

The overwintering beetles attain their maximum numbers in the fields about the middle of June. The number of beetles taken at baits varies from day to day depending upon the weather. Very few beetles are attracted to baits when the weather is cool, rainy, or overcast. Relatively few beetles appear on the surface before the last week in May and they do not come to baits in any number until about June 8 (Table 4).

The beetles of *Agriotes mancus* Say did not live longer than 36 days after oviposition in our cages and none that have lived over the preceding winter have been found in their natural habitat later than June 25. However, the last survivor of several beetles kept in captivity did not die until August 1 after having been caged for 50 days (Table 5). Such data as we have ob-

TABLE 5

*Length of Life of the Beetles*  
*Agriotes mancus Say*

Confined	Died	Length of life in days
6-12-34	6-18-34	6
6-12-34	6-20-34	8
6-12-34	6-20-34	8
6-12-34	6-20-34	8
6-12-34	6-20-34	8
6-21-34	6-30-34	9
6-18-34	6-27-34	9
6-12-34	6-22-34	10
6-18-34	6-30-34	12
6-12-34	6-25-34	13
6-12-34	6-26-34	14
6-12-34	6-28-34	16
6-12-34	6-29-34	17
6-12-34	6-29-34	17
6-12-34	6-30-34	18
6-12-34	6-30-34	18
6-12-34	6-30-34	18
6-18-34	7-7-34	19
6-12-34	7-2-34	20
6-12-34	7-2-34	20
6-12-34	7-4-34	22
6-12-34	7-4-34	22
6-12-34	7-4-34	22
6-12-34	7-7-34	25
6-12-34	7-7-34	25
6-12-34	7-11-34	29
6-12-34	7-14-34	32
6-12-34	7-16-34	34
6-12-34	7-16-34	34
6-12-34	7-18-34	36
6-12-34	7-18-34	36
6-18-34	8-1-34	44
6-12-34	8-1-34	50

tained indicate that the beetles do not live over a second winter. The males do not live as long as the females, according to data based on observations of the beetles which died in cages during 1934.

During 1933 approximately 68 per cent of the beetles of *Agriotes mancus* Say which were taken at clover baits were males. During 1934 about 75 per cent of those taken were males. On the other hand, female beetles of this species form the larger part of those caught in flight on sticky shields. Limited data obtained show that about four-fifths of the beetles so caught are females.

Large shields made of canvas and spread with tanglefoot were first used in 1927 to catch the adults of *Agriotes mancus* Say and to obtain information about the time and direction of their flight. The canvas was fastened to wooden frames which were faced into the prevailing southwesterly wind. Beetles were caught only on fair days when the wind blew from the west or southwest. They were mostly caught at distances from  $1\frac{1}{4}$  to 3 feet above the soil surface. In order to study more accurately the flight of the beetles another type of shield was erected. This was so arranged that it presented one surface directly across the wind and another directly parallel to the direction from which the wind was blowing. The beetles were nearly all trapped on the surface facing across the wind and again beetles were caught only on bright days when the wind was from the west or southwest. Later screenwire spread with tanglefoot was used and so arranged as to face stationary wings 6 by 10 feet in two directions, namely, west and southwest (Plate III). Comparatively few beetles of *Agriotes mancus* have been taken on these sticky surface traps (Table 3) and most of these have been within 3 feet of the soil surface. The greater number of beetles taken were caught from about 10 a.m. to 2 p.m. Elaterid beetles other than *Agriotes mancus* have been taken in some numbers at these traps.

In contrast to the few beetles caught on the sticky shield type of traps, many have been taken at clover baits near the traps. This would indicate that although abundant, the beetles of this species fly but little. Many beetles have been observed to move about upon the soil's surface and to explore cracks and crevices apparently seeking mates. In plowed fields the exodus is by running over the surface and dissemination is largely by this method rather than by flight.

Eggs were laid on June 14 and until July 9 (Table 6). The longest oviposition period observed for any beetles of this species was 23 days and the longest time elapsing between oviposition and death was 16 days (Table 7).

The beetles used to obtain data for Table 7 were placed in individual cages and fed on clover and honey water. Observations were made daily and when a beetle died at the beginning of the oviposition period, it was replaced by another beetle from which data could be obtained.

Eggs of the confined beetles *Agriotes mancus* were laid usually just beneath the surface of the soil or beneath clover on the surface. Eggs were found in nature oviposited in cavities in the soil and beneath the leaves of clover used to trap the beetles. They are deposited both singly and in clusters. The average incubation period based on data obtained from observations

of 31 eggs laid June 20, 1934, is 20.6 days (Table 8). The first eggs of this lot hatched in 19 days time and the last hatched in 27 days. It is interesting to note that approximately 90 per cent of these eggs hatched. The approximate incubation period of nine groups of eggs (Table 6) ranged from 13.6 to 22.5 days with the average time for all the groups being about 18 days.

TABLE 6

*Oviposition and Incubation of Agriotes mancus Say*

Group number	Date of oviposition	Incubation period	Average incubation period
1	June 14	2 eggs 14 days	17.8 days
		2 " 15 "	
		12 " 18 "	
		9 " 19 "	
2	June 15	1 " 12 "	18.1 days
		1 " 13 "	
		1 " 15 "	
		35 " 17 "	
		10 " 18 "	
		7 " 25 "	
		3 " 20 "	
3	June 19	16 " 13 "	16.7 days
		19 " 14 "	
		47 " 16 "	
		27 " 20 "	
		8 " 21 "	
		1 " 30 "	
		1 " 34 "	
4	June 20	40 " 12 "	13.7 days
		26 " 13 "	
		9 " 15 "	
		10 " 19 "	
		3 " 20 "	
5	June 23	7 " 22 "	22.5 days
		6 " 23 "	
6	July 2	4 " 14 "	19.8 days
		2 " 15 "	
		5 " 17 "	
		5 " 18 "	
		5 " 19 "	
		22 " 21 "	
		15 " 22 "	
7	July 4	1 " 14 "	19 days
		3 " 16 "	
		1 " 18 "	
		7 " 20 "	
		4 " 21 "	
8	July 6	1 " 15 "	17.6 days
		4 " 16 "	
		11 " 16 "	
		18 " 19 "	
9	July 9	1 " 11 "	21.1 days
		6 " 19 "	
		19 " 21 "	
		9 " 22 "	
		6 " 24 "	

TABLE 7

*Oviposition and Subsequent Life History of Agriotes mancus Say*

Date caged	Date of death	Days between confinement and oviposition	Oviposition period days	Total eggs	Days between oviposition and death
6-18-34	8-1-34	7	21	31	16
6-12-34	6-25-34	13	1	14	0*
6-12-34	7-4-34	13	1	2	7
6-12-34	7-18-34	13	23	60	0*
6-12-34				59	
6-12-34	7-16-34	15	19	9	0*
6-21-34	7-14-34	18	14	11	0*
6-12-34	7-7-34	11	9	7	5
6-12-34				33	
6-18-34	7-16-34	14	1	5	12
6-18-34				7	
6-20-34	7-7-34	12	1	3	5
6-20-34				36	
6-20-34				16	
6-20-34				14	
6-20-34			14	51	
6-12-34	7-18-34	27	7	3	2
6-12-34				13	
6-12-34				10	
6-12-34	8-1-34	38	5	4	7
6-18-34	6-27-34	7	2	31	0*
6-12-34	7-16-34	7	16	35	5

\* Oviposition may have been completed the day previous.

The data contained in Table 8 were obtained from records of 31 *Agriotes mancus* which were laid on the night of June 20, 1934. The adult beetles were isolated on egg-free soil the afternoon of June 20, 1934. A total of 31 eggs was removed from the soil the morning of June 21, 1934. The 31 eggs were placed in a container to observe the earliest, latest, and average incubation period. The hatchability of the eggs was also obtained.

Larvae of *Agriotes mancus* Say are so tiny when first hatched that it is difficult to observe them in their natural soil environment. Newly hatched

TABLE 8

*Incubation and Percentage of Hatch of Eggs of Agriotes mancus Say*

Date eggs laid	Hatching dates of larvae	Number larvae hatched	Days of incubation period			Per cent hatch
			Earliest	Latest	Average	
6-20-34	7-9-34	15	19	27	20.6	90.32
	7-11-34	6				
	7-12-34	2				
	7-14-34	4				
	7-17-34	1				

larvae of this species are only about 1.8 mm. in length and .18 mm. in maximum width. During their first year the larvae seldom attain a length of more than a few millimeters (Table 9). Since the hatching period is vari-

TABLE 9

*Growth Record of the Young Larvae  
of *Agriotes mancus* Say\**

Length in mm.	Length in mm.
9	9
6	6.6
6	4.5
3.6	8.0
4.8	8.4
6.3	8.4
6.3	5.4
9	7.5
4.7	7.5
6	6.1
6.7	5.9
5.1	6.0
6	

Average length 8.5 mm.

\* Hatched July 21, 1934. Measured November 14, 1934.

able and the larvae consume variable amounts of food, the size of the individuals at the end of the first summer is variable. It is conceivable that by fall of the first year most of the larvae in nature may yet be small if we may judge by the size of first year larvae reared in the laboratory. It is probable that these small larvae would not be seen unless special effort was made to find them.

No existing record can be found of larvae of *Agriotes mancus* Say having been observed in their natural environment from egg to pupal stage. However, Pettit (1872) was of the opinion that the larval stage did not last longer than three years. Comstock and Slingerland (1891, p. 253) record a larva of this species living in a cage two years and two months. Judging from their description, the larvae were hatched during the summer preceding the date of caging, for on May 10 they ranged from 6 to 10 mm. in length.

The knowledge that there is a range in size from about 4 mm. to 9 or 10 mm. during the first season of growth serves as a basis for timing the length of life in the larval stage. Larvae reared in the laboratory do not conform exactly to the life cycle of those living in their natural environment. Yet there is little difference in size between larvae reared inside during the first season of growth and those of the same age living in their natural habitat. This is borne out by a study of larvae taken in the field late in the fall which have approximately the same range in length as those reared in the laboratory. Larvae of a size ranging from 6 to 10 mm. in length pass through at least another year before pupation. Although larvae reared in the labora-

tory require a shorter time to reach the pupal stage than those living in nature, an estimate may be based on this somewhat artificial larval period for an approximation of the time required to complete the larval stage. Data obtained by rearing this species from egg to adult are as follows: eggs of this species laid June 17, 1931, hatched on July 6, 1931. The first of these pupated on July 3, 1933. Six had pupated before July 27, 1933. Two of these larvae did not pupate until the following April. Larvae which hatched on July 31, 1932, were fully formed beetles on June 8, 1934.

Larvae from eggs laid at the same time by the same individual hatch over a considerable period of time (Table 6). They are not all the same size at any given time up to pupation and they do not pupate on the same date. Beetles formed from these larvae do not all emerge from the pupae at the same time and the beetles when fully formed are not all of the same size. Some larvae from eggs deposited at the same time live through two winters, and others may live another year before pupation. Regardless of the length of time required to complete the larval life of this species, pupation occurs in nature during late July, August, and September. Why the time required to complete the life cycle varies a whole year is problematical. Larvae kept at low temperatures in the laboratory do not develop as swiftly as those kept at higher temperatures. The amount of moisture in the soil is important to the growth of the larvae. Larvae reared in containers in which soil was kept well moistened attained almost twice the length at the end of the first season as those kept in containers in which the soil was just moist enough to support life. Certainly the amount of food available is important to growth of the larvae. Larvae placed in sterile potato agar and reared under entirely sterile conditions grew but little even though the agar contained abundant potato pulp upon which these larvae ordinarily thrive. Apparently something necessary for growth was lacking in the agar. The possibility that bacteria present in the soil were absent from the agar has been suggested as an explanation of the lack of growth of the larvae, and also that vitamins are destroyed during the process of sterilization. Be that as it may, the larvae do not thrive under entirely sterile conditions in potato agar.

A search of the literature on wireworms has failed to reveal any existing record of the number of larval instars for *Agriotes mancus* Say. Roberts (1921, pp. 194-198) discusses the larval instars of *Agriotes obscurus* Esch. He records eight larval instars for *Agriotes obscurus*. Great difficulty has been experienced in finding the cast skins of *Agriotes mancus* and in telling just when the molts occur. The young larvae are tiny and almost as white before the first ecdysis as just after the first molt has occurred. One method of being certain of the time of ecdysis is to actually observe the process. This requires constant attention especially when larvae are kept in soil. During the summer of 1934 considerable effort was made to observe the first ecdysis. In order to facilitate observation the somewhat transparent rearing media of potato agar was used. The first attempt ended in failure because of bacterial contamination. Afterwards sterile agar was used in sterilized test tubes plugged with sterile non-absorbent plugging cotton. In these tubes the larvae could be constantly observed. An egg sterilized for one minute in a

solution of corrosive sublimate ( $\text{HgCl}_2$ ) one part to 800 parts distilled water and then rinsed in distilled water was placed in each sterilized test tube used. The tubes were replugged with the cotton and eggs were then allowed to hatch. Little contamination resulted. Even in this nearly transparent medium the larvae could scarcely be observed. From some sixty tubes maintained, but two records of the first ecdysis were obtained beyond reasonable doubt. A further difficulty encountered in the use of the sterile test tube potato agar method is that the larvae do not grow normally after the first ecdysis. The problem yet to be solved in the use of this method is what must be added to the agar and what condition of light and temperature must be maintained to promote a normal growth of larvae.

Two larvae of *Agriotes mancus* reared in the potato agar required 61 to 66 days respectively to complete the first larval instars. Skins from the first larval ecdysis were found in soil cages in 57 and 66 days. Thirty-four days was the average time required to complete the second larval instar. A record of ecdyses for larvae of *Agriotes mancus* is shown in Table 10. Data shown

TABLE 10

*Ecdysis of Agriotes mancus Say. Records of Individual Larvae*

Larvae number	Hatching date	Date of molt
1	6-29-34	10-9-34 and 11-6-34
2	6-29-34	10-1-34
3	6-5-34	9-6-34 and 10-9-34
4	6-29-34	10-9-34
5	7-3-34	9-6-34
6	6-21-34	11-6-34
7	7-24-34	10-9-34
8	6-20-34	10-9-34
9	6-30-34	8-25-34 and 11-6-34
10	7-3-34	11-16-34
11	8-6-34	10-6-34
12	8-1-34	10-6-34

in this table are of ecdyses without reference to the number of the larval instar except that larvae numbered 5, 11, and 12 are of the first instar and those numbered 1, 3, and 9 are of the first and second instar.

Data on larval instars after the first two are meager. Ecdysis does not occur at the same time for larvae of the same age. There are probably three larval instars the second summer and one the third summer so that in all a total of 6 and possibly 7 larval instars occur.

Exact data on the length of the pupal stage of *Agriotes mancus* Say are difficult to obtain. It is necessary to remove the soil to study the pupae in their natural habitat and this may disturb the life processes. Data obtained from field and laboratory observations indicate that the duration of the pupal stage is somewhat variable. They are found in their pupal cells in the

TABLE 11

*Occurrence of Pupae of Agriotes mancus Say*

Year	Month	Dates Taken
		Day
1926	August September	5, 8, 10, 19, 20, 27 8
1927	July August September	26 6, 10 12
1928	July August September	20 13, 14, 17 2, 7
1929	August September	4, 9, 14 11
1930	August September	8, 9, 18 2, 14
1931	August	8, 9, 10, 17, 18
1932	August September	16, 17 1, 2, 3
1933	August September	15 3, 8
1934	August September	6, 14, 16, 20 3, 14, 15

soil from July 20 until the middle of September (Table 11). However, pupae of this species are most abundant about the middle of August. Newly formed pupae taken from the soil on July 20 and 26 had transformed by August 4 and 6 respectively. On August 5, 1926, there were many newly formed pupae in the soil. Digging was continued at short intervals of one or two days and many of the pupae were transforming on August 19 and 20.

Under laboratory conditions a pupa formed on July 3 transformed to the beetle stage on July 19, an abnormal time of year for both pupation and emergence in nature. Another larva reared in the laboratory pupated on August 18 and emerged on August 30. Six pupae were taken from their soil environment on August 3. Three of these emerged on August 18, two on August 24, and one on September 5. The soil became dry after August 18 and this may have been responsible for the length of time of the pupal stage in the two latter cases. The average length of time for pupation according to data obtained is approximately seventeen days and is probably less under favorable natural conditions.

The life history of *Agriotes mancus* Say as shown in Figure 13 does not represent a complete picture of the life cycle as it occurs under favorable conditions. It shows rather what happens in cleanly cultivated fields; whereas under other conditions the third year overwintering beetles lay eggs which

hatch into larvae of a new generation thus continuing the life cycle indefinitely. In nature the life history occupies three or four years. That is, if larvae do not pupate during August or September of the third year, they do not pupate until August or September of the fourth year. Eggs laid in June hatch in July. Larvae of these feed until the end of the season, hibernate and resume feeding in the spring. The second season the majority of them feed heavily and attain the greater part of their growth. These then spend a second winter in the soil, come out of hibernation in the spring, feed and grow until late July or August when pupation occurs and transformation to the beetle stage occurs by early September. A few of this generation hibernate overwinter, come up in the spring, feed during the summer, transform and emerge as beetles by September of the fourth year (Fig. 13). The above facts are founded on results of observations in the field and records of reared specimens kept over a period of several years.

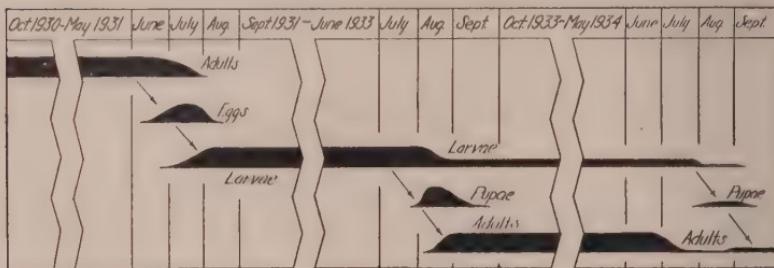


FIG. 13. Life-history chart of the wheat wireworm *Agriotes mancus* Say.

#### IMPORTANT POINTS IN LIFE HISTORY OF THE WHEAT WIREWORM, *Agriotes mancus* Say

Adults have been found in Maine from August 5 to October 26 in the earthen cells beneath the soil surface. The depth at which they are found varies from about 4 to 8 inches. They remain in the pupal cells during the winter, or leave them and enter the soil outside the cells, or hibernate beneath debris in or about the fields. Occasionally the beetles are found crawling on the surface during April and May but the height of their activity begins about the first of June. Their principal method of dissemination is by means of crawling on the surface of the soil although some take to flight. Mating occurs during late May and during June. Egg laying occurs in June and during the first part of July. The tiny eggs are laid in

cracks and crevices in the soil and beneath debris on the surface. The time required for the eggs to hatch is about 18 days. The larvae or wireworms are tiny when first hatched and are yet quite small by the time they hibernate late in the fall of the first year. The second summer is spent by the wireworms in active feeding and growth and it is during this second season that they do extensive injury to crops. They become about three-quarters of an inch in length by the end of the second summer and again hibernate. They feed again during the third summer until August, when they make oval cells in the earth and inside of these cells most of the wireworms change to pupae. The pupal stage lasts about 17 days and then the change from pupae to beetles takes place, ending the life cycle in about three years. Some of the wireworms do not transform to beetles until August of the next year, requiring nearly four years to complete the life cycle.

### THE GENUS *Melanotus*

Five named species of elaterid beetles belonging to the genus *Melanotus* have been collected in Maine. They are *Melanotus castinipes* Payk., *Melanotus communis* Gyll., *Melanotus fissilis* Say, *Melanotus pertinax* Say, and *Melanotus leonardi* Lec.

In general, specimens of beetles of the genus *Melanotus* (Plate II, D) are dark brown or black in color. Those measured range from about 10 mm. to 22 mm. in length. The characters used by Blatchley (1910, p. 744) to distinguish the adults of this genus are: "Moderate-sized click-beetles, usually uniform dull brown in color and having the clypeus margined in front, antennae serrate, with the first joint broad, the second and third variable; prosternum lobed in front, the sutures double and concave on the outer side; hind coxal plates gradually dilated inwards and toothed above the insertion of the thighs; tarsi not lobed beneath, the claws with distinct comb-like teeth. The males usually have the antennal joints pilose or clothed with erect bristling hairs."

The eggs obtained from beetles belonging to the genus *Melanotus* are similar to those described for *Agriotes mancus* Say. They are slightly larger in size but they are of approximately the same form as those of *Agriotes mancus*.

Wireworms of the genus *Melanotus* are among our commonest large species. They are shiny dark brown in color. The largest of them attain a length of approximately 35 mm. In general form they are similar to the larvae of *Agriotes mancus* Say, described on pages 27 to 30. However, they attain a greater size when fully mature, and are darker in color. The ninth abdominal segment is different from that of the larvae of *Agriotes*

*mancus*. The dorsal surface is somewhat flattened and the lateral margins of the terminal abdominal segment are lobed in larvae of the genus *Melanotus* (Fig. 14A and C). Small dark tubercles interspersed by small round pits are present on the caudal portion of the dorsum and are most numerous near the tip of the segment. The dorsal surface of the segment is finely reticulated. In lateral view the ninth and tenth abdominal segments (Fig. 14B) are similar in form to those of the larvae of *Agriotes mancus*, but the eye-like invaginations of the latter are lacking in the larvae of *Melanotus*. The form of the ninth abdominal segment of these larvae distinguishes them from larvae of other genera of Elateridae found in Maine. A general size range of these larvae is shown in Plate III, B.

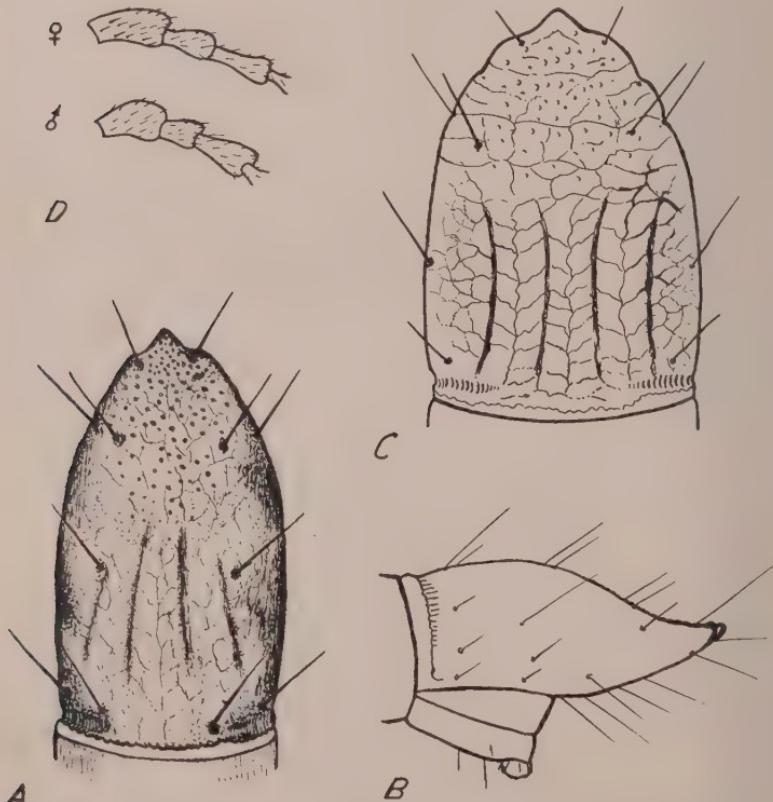


FIG. 14. A. Dorsal view of the ninth abdominal segment of *Melanotus* larva.  
 B. Lateral view of ninth and tenth segments of *Melanotus* larva.  
 C. Another form found in the ninth abdominal segment of the larvae of the genus *Melanotus*.  
 D. Antennae of male and female of *Ludius cylindriformis*.

### THE GENERAL DESCRIPTION, LIFE HISTORY, AND HABITS OF THE GENUS *Melanotus*

*Melanotus* larvae having the ninth abdominal segment of two different forms have been taken in Maine (Fig. 14A and C) and probably represent two species. The larvae of these two species present in Maine, cannot be identified in the larval stage beyond the genus designation of *Melanotus*.

Elaterid beetles of the genus *Melanotus* (Plate 4A) are among the most common elaters found on flowers and foliage. They are strong fliers and were often captured on sticky surfaces used as traps for flying beetles. The writer has collected adults of this genus from the heads of growing timothy, from flowers of plum and the wild rose and from foliage of grass, chokecherry, witch hazel, and wild rose. They were taken from the soil at Thorndike, Maine, as early as May 8, and have been found in the soil at Monmouth, Maine, in late July and during August. Certain species inhabit woodlands. Larvae of the genus *Melanotus* have been taken from rotting wood in the forest and from beneath the bark of pine logs. Adults were found beneath the bark of beech trees. These beetles are attracted to baits of honey and water but are not attracted to baits of clover placed on the soil. They are reported to suck the juices of plum fruits.

*Melanotus* beetles taken on July 13 laid eggs which began hatching on August 22. Eggs secured on July 2 hatched on July 31. It is probable that oviposition occurs somewhat later in the season than it does for *Agriotes mancus*. The larvae when first hatched are tiny, being about 2 mm. in length. Larvae from about 10 mm. to 35 mm. long have been taken from the soil of various Maine farms. It is difficult to grade the larvae into sizes according to age and probably like *Agriotes mancus* there is considerable variation in the size of larvae hatched from eggs laid at the same time.

The duration of the larval period of *Melanotus communis* Gyll. is said by Comstock and Slingerland (1891, p. 263) to be at least three years. This conclusion is based on the length of time between confinement of the larvae in soil cages and emergence of the beetles. A review of the literature concerning this genus has failed to reveal any record of the larvae of *Melanotus* having been reared from the egg stage to maturity. Several hundred larvae of *Melanotus* sp.

have been kept in soil cages in the laboratory at Orono for various lengths of time. Specimens approximately 20 mm. long when taken which were kept for two years died before pupation. A specimen kept from August, 1927, to October, 1931, pupated but did not develop as a fully formed beetle. Pupation in nature occurs during July and August. Probably conditions in the laboratory were somewhat different from the conditions under which the insects naturally live. At any rate, pupation of larvae of this genus occurred during a month of the year when this event has not been observed to take place under natural conditions in Maine. Since the larvae are but a little more than 2 mm. in length when they hatch from the egg it is improbable that such slow-growing insects could attain a length of about 35 mm. and reach maturity in less than three years time. If we may assume that larvae reared were a year old when placed in our cages, the life history is of more than three years duration under laboratory conditions.

Details of the life history of larvae of the genus *Melanotus* which we have observed are as follows: The adults are found fully formed in the pupal cells in the soil largely during the month of August and occasionally in September. The adults become active in early spring and have been taken in the fields from late in April until the middle of July. They are strong fliers and are the most common of all elaterids taken on sticky shields, flowers, and foliage during the months of June and July. They are also attracted to liquid baits of water and honey but have never been taken at clover baits which are attractive to *Agriotes mancus* Say and *Cryptohypnus abbreviatus* Say. Eggs were obtained from adults in July and these eggs began to hatch on the 22nd of August. An occasional pupa of this genus was taken in the field during late July but the majority were found during the month of August. The length of time intervening between the hatching of the egg and the forming of the pupa is unknown.

The wireworms of the genus *Melanotus* are probably second in importance to the wheat wireworm in the amount of damage done to growing crops in Maine. During each year since 1925 the wireworms have been taken in large numbers. During 1929 they were so abundant that they entirely destroyed a large part of the growing corn in two fields of a Western Maine farm. They destroyed completely all plants growing within the infested areas

except weeds of a species of the Amaranth Family. As the season progressed, all food inside the areas being destroyed, the wireworms moved outward, continually increasing the devastated areas. Late in the fall they fed upon the underground parts of the nearly mature corn roots and other underground parts of the plant. They were so numerous in one locality under observation that nearly a hundred larvae were taken from an immature ear of corn which had fallen to the ground. Beans, cucumbers, and cabbages have been severely injured during the last few years by these wireworms. In fact these insects appear to be general feeders, although they are not ordinarily found in great numbers attacking potato tubers in the late summer and fall.

Field studies of the habitat of *Melanotus* sp. have revealed that a light, relatively dry soil is favorable to the maximum abundance of the larvae. A certain amount of soil moisture, however, is an important factor in the survival of the larvae. They are often abundant in the sandy loam of the coastal regions of Southwestern Maine and in the valleys of the Kennebec and Sandy Rivers. (See Map, Fig. 1). However, larvae of *Melanotus* sp. have been taken in the same habitat as those of *Agriotes mancus* and are quite generally spread over the southern half of Maine.

### THE GENUS *Ludius*

The genus *Ludius* contains more species of adults recorded from Maine than any other genus of Elateridae. Larvae of *Ludius* are not so well known as the adults and consequently the field worker is handicapped because specific determinations of the larvae are often impossible. In general, wireworms of this genus alone are not abundant enough within a given area to be a factor in the economic production of crops. They are, however, associated with wireworms of other species in damaging plants and thus add to the total of the injuries caused by wireworms to agricultural crops in Maine.

Adults of this genus have been found in widely separated areas in Maine. They are common over the central portion of the State and have been collected as far north as Washburn in Aroostook County (see map Fig. 1). The larvae of the genus are found associated with the larvae of *Agriotes mancus* Say in the heavier

types of soil and also inhabit sandy or light loam soil. Their preference in general is for a soil containing some clay, but apparently they prefer a somewhat better drained soil than that which is the chief habitat of *Agriotes mancus*.

Certain details in respect to the life histories of the species of the genus *Ludius* recorded from Maine (see list of Maine elaterids) are little known. However, a start has been made with this genus and some interesting facts have been noted. Larvae and adults both occur in the soil from early spring until late fall and the larvae have been taken from the soil during winter. A larva of *Ludius insidiosus* Lec. reared in the laboratory pupated on May 13 and emerged as a beetle on May 22. The adults are commonly taken on foliage and on tanglefoot traps during June and early July. They are apparently strong fliers and have been observed in flight on warm bright days.

#### DETAILED DESCRIPTION OF *Ludius cylindriformis* Hbst.

*Ludius cylindriformis* Hbst. is one of the most common species of the genus met with in the field. The female is much larger than the male, the body is more robust, and the prothoracic disk in the female is nearly equal in width to the elytra at the base, while in the male the prothoracic disk is considerably narrower than the base of the elytra (Plate 4C). The second antennal joint of the female is approximately two-thirds or more of the length of the third antennal segment, while in contrast the second antennal joint of the male is less than two-thirds the length of the third joint (Fig. 14D). The body of the male is also more depressed in a dorsoventral direction than is the body of the female which on the whole is cylindrical in form.

Larvae of the genus *Ludius* resemble those of *Hemicrepidius decoloratus* Say in general body contour. They differ from the latter in that the caudal notch partially enclosed by the caudal processes or urogomphi (Fig. 15A, U) of *Ludius cylindriformis* Hbst. is somewhat smaller and the caudal tubercles are more blunt than *Hemicrepidius decoloratus*. Larvae of *Ludius cylindriformis* have four dorsal setae on the disk of the ninth abdominal segment, and punctures present on the caudal disk of *Hemicrepidius decoloratus* are lacking. Larval specimens of the genus *Ludius* taken in Maine vary in length from approximately 5 mm. to 37 mm. A specimen of *Ludius insidiosus* Lec. attained a length of approximately 30 mm. before pupating May 13, 1933.

#### *Cryptohypnus abbreviatus* Say

*Cryptohypnus abbreviatus* Say, in the adult stage, is a picaceous colored beetle with a greenish bronze cast. The general outline of the body is oblong

ovate in dorsal aspect (Plate IVD). Both the dorsum and the venter are convex and the lateral margins are expanded to form acute angles in cross section. The body, head, and appendages are clothed with short, yellowish, recumbent pubescence. The legs are yellowish. There is some variation in the size of the beetles of this species but the average is approximately 5.5 mm. in length, 2 mm. in width, and 1 mm. from dorsum to venter.

The head is considerably narrower than the rest of the body. The mouth-parts are hypognathous. The eyes are somewhat protuberant and are set beneath the frontal ridge which covers the bases of the antennae and continues as an elevated curved ridge above the base of the labrum. The second and third segments of the antennae are more or less filiform. The middle segments are serrate and the distal segment is subovate and bluntly pointed at the tip.

The prothoracic disk is somewhat broader than long. It is convex in general form and is coarsely punctate with the median basal impression disappearing toward the cephalic margin. The disk as seen in dorsal aspect is narrowed in front, the lateral margins curve outward from the base, the middle is slightly contracted and the caudolateral angles are expanded and produced into subacute, carinated spines which embrace the elytra at their base. The entire disk is coarsely punctate and pubescent.

From the lateral margins the prothorax slopes toward the somewhat shield-shaped and convex prosternum. The prosternal sutures are slightly sinuate on the cephalic portion and curve mesally toward the bases of the legs. The external portions of the coxae of the prothoracic legs are globular, and the trochanters are transverse and so attached to the thighs that the thighs and trochanters are set at a slightly obtuse angle. The tarsus of the thoracic legs are five segmented. All the tarsal segments except the fifth are pubescent and the first and fifth are longer than those intermediate. A pair of simple tarsal claws are attached to the distal end of the fifth tarsal segment. The prosternal spine is nearly cylindrical in form and curves slightly upward to fit into the mesosternal cavity.

The elytra are most densely pubescent towards the lateral margins and tips. Each elytrum has nine longitudinal striae each of which is marked with an irregular row of oval punctures. Intervals between the striae are flat and finely punctate.

The mesosternum is very small and the coxae of the mesosternal legs are somewhat more conical in shape than those of the prosternum. The metasternum is sparsely set with short pubescence on the midventral area. A distinct, median, slightly impressed furrow extends the length of the metasternum. The coxal plates of the hind legs are dilated suddenly and are slightly toothed above the insertion of the thighs. The trochanters are large, transverse and offset somewhat at their junction with the thighs.

Five segments of the abdomen are visible ventrally. A fine pubescence, progressively longer and denser toward the fifth segment, clothes all the ventral surface of the abdomen. The fifth segment is the longest and narrowest of the abdominal segments.

Eggs of *Cryptohypnus abbreviatus* Say are very similar to those of *Agriotes mancus* Say, except that they are somewhat more regular in shape

- FIG. 15. A. Dorsal view of the ninth abdominal segment of *Ludius cylindriformis*.  
B. Frons and nasale of adult of *Cryptohypnus abbreviatus*.  
N. nasale  
C. Dorsal view of the head of a larva of *Cryptohypnus abbreviatus* Say.  
P1. posterior epicranial seta  
P2 and Ps. secondary posterior epicranial setae  
Pa, Pb, Pc. short posterior setae or sensory pegs  
D. Dorsal view of the ninth abdominal segment of *Cryptohypnus abbreviatus* larva.  
U. urogomphi  
E. Dorsal view of the ninth abdominal segment of *Hemicrepidius decoloratus* larva.  
F. Pupa of *Cryptohypnus abbreviatus*.  
S1, S2, S3. spines  
Pd. prothoracic disk  
Sc. scutellum  
W1 and W2. wings  
L. legs  
1 to 9 abdominal segments

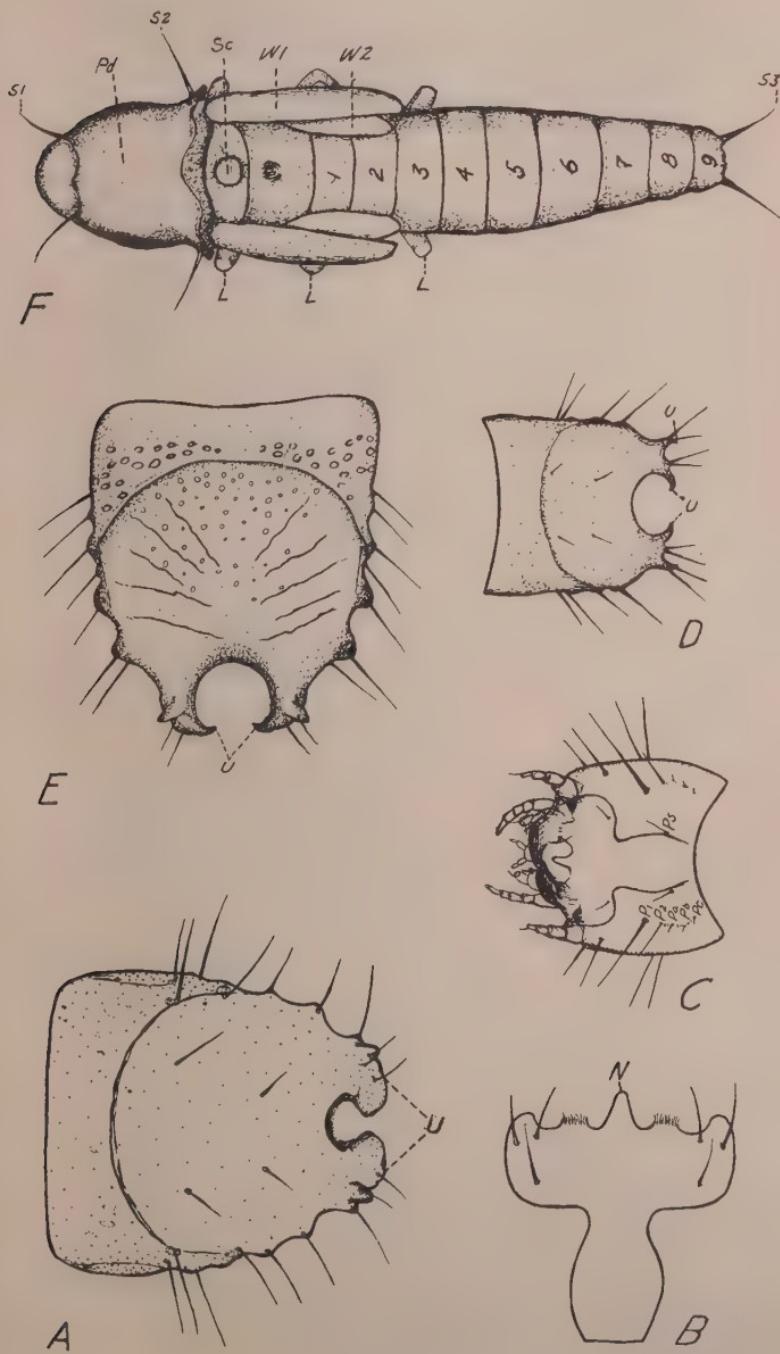


FIG. 15

and more uniform in size. The eggs are glossy white in color and usually oval in shape. They are approximately 400 microns in their minimum diameter and 500 microns in their maximum diameter. Like eggs of *Agriotes mancus* they are protected by a relatively elastic and resistant shell, and become yellowish before hatching.

Larvae of *Cryptohypnus abbreviatus* are among our smallest injurious wireworms. They are from 8 to 10 mm. in length, approximately 1.5 mm. in width and only about 1 mm. in maximum depth when fully mature. Since the body is wider than deep it is subcylindrical in cross section. It tapers slightly from near the middle and longitudinally in both directions and on the whole is more or less fusiform. These larvae are light brown, being somewhat lighter in color than those of *Melanotus* sp. but are not so yellowish as the larvae of *Agriotes mancus*. A narrow, impressed, middorsal line extends from the head to the ninth abdominal segment.

Larvae of this species have heads (Fig. 15C) that are somewhat similar in form to those of *Agriotes mancus* Say. Some twenty odd specimens of *Cryptohypnus abbreviatus* reared to the last instar were characterized by a nasale with a monodentate tip (Fig. 15B, N) extending forward between the bases of the mandibles. However, Böving and Craighead (1931, Pl. 86) illustrate this species as having a trident tip to the nasale. Since the tip of the nasale is often worn the question arises as to whether the dentes on the specimens which we examined were intact. The arc-like arrangement of the epicranial setae (Fig. 15C, P1, P2) and the posterior group (Pa, Pb, Pc) is characteristic of this species. A posterior subdorsal seta (Ps) on either side of the vertex near the epicranial suture is present on the heads of these larvae and absent from those of other larvae examined.

The setal arrangement of all of the abdominal segments, except the ninth in larvae of *Cryptohypnus abbreviatus* is approximately like that of *Agriotes mancus* larvae (Fig. 10F). The larvae of *Cryptohypnus abbreviatus* resemble the young larvae of *Hemicrepidius decoloratus* Say in size and form; although the setal pattern serves to separate the two species.

The ninth abdominal segment of *Cryptohypnus abbreviatus* (Fig. 15D) is of the same general form as that of the larvae of *Hemicrepidius decoloratus* and *Ludius cylindriformis*. It differs from *Hemicrepidius decoloratus* in lacking the punctures and in having setae present on the flattened dorsal portion or disk of the ninth segment. The urogomphi are also acute and are distinctly recurved at the tip while in *Hemicrepidius decoloratus* they are somewhat blunt and straight. The ninth abdominal segment of *Cryptohypnus abbreviatus* larvae differs from that of *Ludius cylindriformis* in the more acute and curved urogomphi.

Pupae of *Cryptohypnus abbreviatus* Say (Fig. 15F) are whitish in color. They are about 7.5 mm. in length and 1.6 mm. in width. The laterocephalic angles of the dorsal shield of the prothorax are produced into long spines which project forward (S1). The caudolateral angles are likewise set with spines which project outward and upward (S2). The head, three thoracic, and nine abdominal segments are present on the dorsal aspect. The caudal segment of the abdomen is terminated by a pair of spines or cerci-like

processes. Wings, legs and other appendages are free from any secondary attachment to the body; that is, the pupae are of the type exarate.

#### LIFE HISTORY AND IMPORTANCE OF *Cryptohypnus abbreviatus* Say

Elaterid beetles of *Cryptohypnus abbreviatus* Say were active at baits of sweetened graham flour dough on May 29, 1933. On June 12 these beetles laid eggs, some of which were hatching on June 16. One individual reared from these eggs was a fully formed beetle by late October of 1933. Eggs were also obtained and larvae hatched on June 18, 1931. Larvae from these died when apparently fully mature in November, 1931. Pupation occurs under natural conditions during the month of August and the beetles from these normally lay eggs the following spring. Larvae of this species are but approximately 1.5 mm. in length and 0.1 mm. in width when they are first hatched. They are present in the soil during spring, summer, and fall. The habitat of *Cryptohypnus abbreviatus* is more nearly like that of *Agriotes mancus* than any other species, although the larvae are sometimes found in fairly dry soil. Probably the greatest damage from larvae of this species is done to planted potato seed pieces.

#### *Hemicrepidius decoloratus* Say

A wireworm commonly found in fields and gardens of Maine is *Hemicrepidius decoloratus* Say. The head and prothorax of beetles of this species taken in Maine are piceous and the bodies are dark brown. The size varies from approximately 9 mm. to about 17 mm. in length. The body is densely pubescent and depressed in a dorsoventral direction. Antennae are modified serrate. The fourth tarsal joint is small and obscure, the fifth is long and slender, and the tarsal claws are simple.

The ninth abdominal segment is flattened on the caudal two-thirds of its dorsal surface (Fig. 15E). The flattened area is characterized in the cephalic portion by small round punctures and irregular, slightly convergent lines. The urogomphi (u) are well separated and partially enclose an oval area between them. They are two-pronged; one prong curves mesad, the other extends dorsad. Six setae (Fig. 16A) are set in a transverse row a little caudad of the middle of each dorsal sclerite of the sixth, seventh, and eighth abdominal segments. Paired lateral setae are present on the epicranium (Fig. 16D, L1 and L2). A long, posterior, epicranial seta is set in a narrow, longitudinal depression on either side of the vertex (Fig. 16B, P1). A row of four short, peg-like setae or sensoria are located in the depressions caudad to each long seta (Fig. 16B, P2, Pa, Pb, and Pc). The frons (F) is truncate at its caudal margin and the nasale (N) is tridentate.

- FIG. 16. A. Lateral view of a middle abdominal segment of *Hemicrepidius decoloratus* larva.  
Sp. spiracle
- B. Dorsal view of head of *Hemicrepidius decoloratus* larva.
- |                 |                            |
|-----------------|----------------------------|
| N.              | nasale                     |
| F.              | frons                      |
| V.              | vertex of epicranium       |
| P1.             | posterior epicranial setae |
| P2, Pa, Pb, Pc. | secondary epicranial setae |
- C. Dorsal view of *Limonius agonis* ninth abdominal segment of larva.
- D. Lateral view of the head of *Hemicrepidius decoloratus* larva minus lower mouthparts.
- |                 |                                  |
|-----------------|----------------------------------|
| P1.             | posterior epicranial setae       |
| P2, Pa, Pb, Pc. | secondary setae epicranial setae |
| A1.             | anterior epicranial setae        |
| L1 and L2.      | lateral setae                    |
- E. Lateral view of eighth, ninth, and tenth abdominal segments of *Limonius agonis*.  
I to VIII. setae of the tergum
- F. Dorsal view of the ninth abdominal segment of a larva of the subtribe Adrastina.
- G. Lateral view of the ninth and tenth abdominal segments of a larva of the subtribe Adrastina.
- |      |                         |
|------|-------------------------|
| A9.  | ninth abdominal segment |
| A10. | tenth abdominal segment |

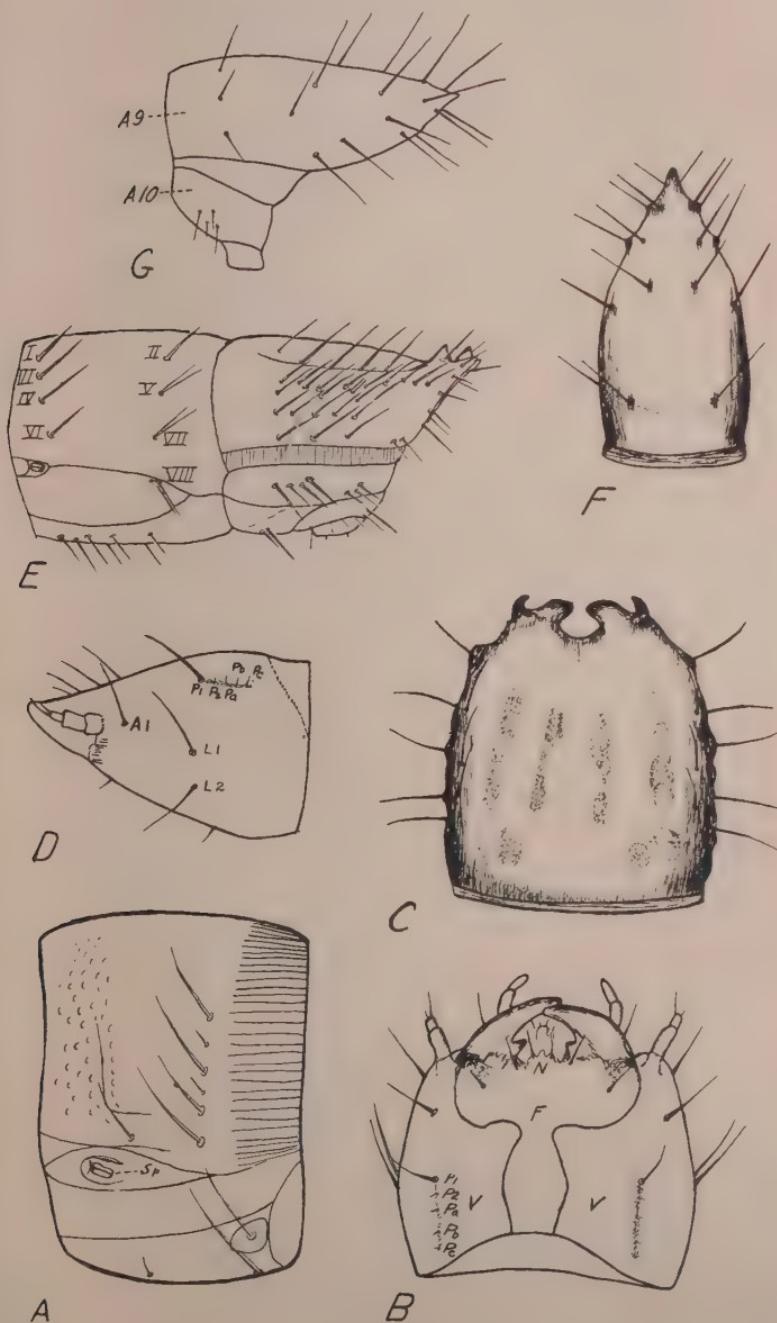


FIG. 16

GENERAL DESCRIPTION, LIFE HISTORY, AND HABITS OF  
*Hemicrepidius decoloratus* Say

Larvae of *Hemicrepidius decoloratus* Say are robust and yellowish in color. Full-fed, extended larvae are almost perfectly cylindrical in form. They are bright yellowish brown in general color and the head and tip of the caudal segment are reddish brown. Larvae of this species taken measured from approximately 8 to about 23 mm. in length. They may be distinguished from other wireworms ordinarily found in the agricultural regions of the State by the form of the ninth abdominal segment (Fig. 15E) and the arrangement of the setae on the sixth, seventh, and eighth abdominal segments.

There are few known facts concerning the life history and habits of this species recorded from Maine. Adults of *Hemicrepidius decoloratus* Say have been taken on sticky-shield traps during June and July for the past 5 years. They are strong and active fliers but have never been observed to run about on the surface of the soil as do the adults of the wheat wireworm, *Agriotes mancus*.

Larvae of *Hemicrepidius decoloratus* are quite common and attack a wide variety of vegetation including most of the important field and garden crops. No severe infestation of any crop by this species has been found. Damage done by these insects is scattered so that superficially it appears insignificant. Actually the total loss caused by wireworms of this species to plants grown in Maine undoubtedly is considerable.

THE GENUS *Limonius*

Adults of *Limonius agonis* Say and *Limonius plebejus* Say have been taken in Maine. These beetles are of a yellowish brown color with the thorax and head piceous. They are about 10 mm. in length and resemble the males of *Ludius cylindriformis* Hbst. (Plate IV C) in general appearance. However, their small size, the fact that the prothoracic disk is very dense and finely punctate and that the body as a whole is sparsely pubescent distinguish them from males of *Ludius cylindriformis*.

The eggs and pupae of *Limonius agonis* have not been taken in Maine according to any records found. Full-fed mature larvae of *Limonius agonis* attain a length of approximately 20 mm. and a width of about 2.15 mm. and become approximately 1.75 mm. in depth from dorsum to venter. They are of the form described as subcylindrical, being somewhat flattened on the

venter. A middorsal impressed line extends the length of the thorax and the first eight abdominal segments. They resemble the larvae of *Hemicrepidius decoloratus* Say in form and color although the punctures on the dorsum of the abdominal segments are much coarser in *Hemicrepidius decoloratus* than they are in *Limonius agonis*. The form of the ninth abdominal segment is much the same in *Limonius agonis* (Fig. 16C) as that of *Ludius cylindroformis* Illst. and *Hemicrepidius decoloratus* but differs from the latter in having the urogomphi broader and from the former in having a greater abundance of setae on the caudal and lateral surfaces of the ninth abdominal segment (Fig. 16E). Larvae of *Limonius agonis* differ from all other elaterid larvae examined thus far, in having setae V, VII, and VIII of the first eight abdominal segments binate (Fig. 16E).

#### LIFE HISTORY AND HABITS OF THE GENUS *Limonius*

Larvae of the genus *Limonius* are sometimes very destructive to field and garden crops in certain Maine localities. They are found mostly in the sandy soil of the river valleys and inhabit soil which is at least moderately well drained. Larvae of this genus usually found injuring crops in Maine have been determined as belonging to the genus *Limonius* but specific determinations have not yet been obtained. However, they are probably not the larvae of the eastern field wireworm, *Limonius agonis* Say, which is comparatively rarely taken. The planted seed pieces of potatoes and other field and garden crops were affected by these wireworms in the upper valley of the Androscoggin and in the Piscataquis valley during 1934. Dahlia bulbs were destroyed by them near Lewiston in 1932 and they are commonly taken on wild radish, *Raphanus raphanistrum*, which they sometimes prefer to corn. The life history of this species is imperfectly known at the present time.

#### *Adrastina*

A larva of the subtribe *Adrastina* was taken with a large number of the larvae of *Agriotes mancus* Say during August, 1926. This specimen resembles those of *Agriotes mancus* in form and color. It is approximately 15 mm. in length and 1 mm. wide. This larva differs from those of *Agriotes mancus* in lacking the subdorsal eye like spots on the ninth abdominal segment and in having the caudal apex of the body acute (Fig. 16F and G) instead of bluntly rounded.

A larva of the genus *Oestodes* was taken in August, 1931. This specimen somewhat resembles larvae of *Limonius agonis* Say in form but differs from

FIG. 17. A. Lateral view of the ninth and tenth segments of a larva of the genus *Oestodes*.

S. spines

B. Lateral view of the head of a larva of the genus *Cardiophorus*.

Dm. dorsal portion of the mandible

Vm. ventral portion of the mandible

Oc. ocellus

C. Antenna of a larva of the genus *Cardiophorus*.

1, 2, and 3. antennal segments

Os. oval sensilla

D. A typical abdominal segment of a larva of the genus *Cardiophorus*.

Am. anterior intersegmental membrane

S. segment proper

Pm. posterior intersegmental membrane

Sp. spiracle

Lp. lateral ambulatory papilla

Vp. ventral ambulatory papilla

E. A mid-abdominal segment of a larva of the genus *Athous*.

T. tergum

Sp. spiracle

F. Lateral view of caudal segments of the abdomen of a larva of the genus *Cardiophorus*.

9t. tergum of the ninth abdominal segment

9v. ventrum of the ninth abdominal segment

10. tenth abdominal segment

Ra. retractile appendices

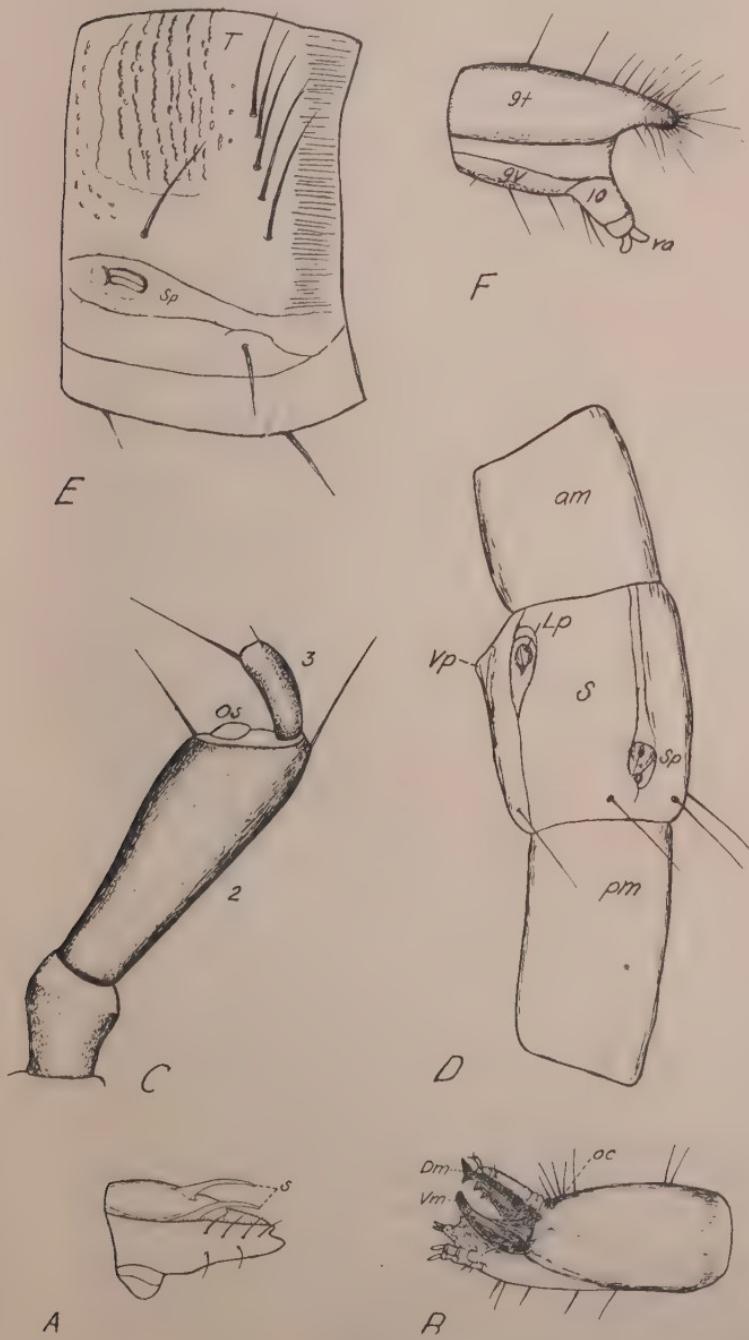


FIG. 17

them in having a pair of curved spines near the lateral margins of the disk of the ninth abdominal segment. The spines or caudal prongs are attached cephalad of the terminal urogomphi and curve backward and downward (Fig. 17A, *v*). The nasale is also bilobed. No other specimen examined has the lateral curved prongs cephalad of the urogomphi on the ninth abdominal segment.

Larvae of both the subtribe *Adrastina* and the genus *Oestodes* are rarely taken in the fields of this State. They are not a factor in the economic production of crops at this time and little is known of their life history or habits.

### THE GENUS *Cardiophorus*

Larval specimens of *Cardiophorus* sp. have been taken occasionally from sandy loam soil at Monmouth, Maine. These larvae are unlike any other wireworms we have taken in Maine. They are long and slender and the abdomen is headlike in appearance. The body appears to be made up of a great many segments due to the division of each abdominal segment into three parts. Larvae of *Cardiophorus* sp. are whitish in color except for the head and prothoracic tergum which is yellowish. Specimens measuring approximately 27 mm. in length and 0.9 mm. in diameter have been taken. These larvae resemble illustrations of *Horistonotus uhleri* Horn, by Böving and Craighead (1931). They differ from *Horistonotus uhleri* in having the retractile appendices sausage-shaped, a single ocellus located behind each antenna (Fig. 17B, *a*), the dorsal half of the mandible sparsely and obtusely toothed, and the ventral half curved inward and upward.

The heads of these larvae are long and depressed (Fig. 17B). They are longer than the prothorax and are yellowish in color. The maxillae and labium are inserted in a deep notch or sinus on the ventral side of the head. The frons is narrowed at the occipital foramen and widens cephalically in the region of the bidentate nasale which is separated from the frons by a suture. The mandibles are deeply cleft into a ventral smooth curved portion (*vn*), and a dorsal dentate portion (*dm*). The three-jointed antenna (Fig. 17C,) is different from that of any other elaterid larvae examined. The proximal joint is small and slightly elbowed. The second is large and somewhat club-shaped. The third joint is small and slightly curved and is located on the distal extremity of the second joint. A small oval sensilla is also present on the distal extremity of the second antennal segment (Os).

The tergum of the prothorax is sclerotized and yellowish in color. It is longer than either the metathorax or mesothorax which are relatively soft and whitish in color. A pair of spiracles are located on the mesothorax near the bases of the legs. Coxae of the thoracic legs are long and extend caudally along the sterna to which they are attached longitudinally. The tibio-tarsi are set with a long spine located near the base of each tarsal claw. The spines resemble the claws in being compressed and slightly curved but they are somewhat more acute at their distal extremities than are the claws.

The abdomen is entirely soft-skinned and each abdominal segment consists typically of three parts, the anterior intersegmental portion (Fig. 17D,

am), the subglobular median or main portion (S), and the posterior inter-segmental portion (pm). The main portions of the abdominal segments are larger than the connecting portions and impart to the abdomen the bead-like appearance. Lateral ambulatory papillae (Lp) and ventral ambulatory papillae (Vp) are present on the abdominal segments, one to eight. A spiracle (sp) is located dorso-caudad to each lateral papilla. The tergum (Fig. 17F, 9t) and the venter (9v) of the ninth abdominal segment are distinctly separated. The tergum of the ninth segment is somewhat acutely extended caudally but is rounded and thickly set with setae at the apex. The tenth segment (10) is attached to the caudal portion of the venter of the ninth segment. This segment is somewhat cylindrical in form and a pair of retractile appendices (ra) is attached at its distal extremity.

The life history of these wireworms in Maine is as yet unknown. Specific determinations can not be obtained for the larval stages. It is only by rearing these larvae to the adult stages that species represented in the larval stage can be determined. Only two or three specimens of these wireworms have been taken during a single season and they are more difficult to rear than certain other wireworms.

### THE GENUS *Athous*

Larvae of *Athous* sp. are subcylindrical in form and yellowish in color. The cephalic and caudal extremities are somewhat darker in color than the rest of the body. They are approximately 30 mm. in length, 3.75 mm. in width, and 2.5 mm. in depth when fully grown. Larvae of *Athous* sp. resemble other members of the tribe Lepturoidini examined, namely, those of *Limonius agonis* Say, *Ludius cylindriformis* Hbst., and *Hemicrepidius decoloratus* Say. The resemblance in form, color, and size is closer to *Hemicrepidius decoloratus* than it is to any other species of the tribe. They may be distinguished from the larvae of *Hemicrepidius decoloratus* by their somewhat larger size, and by the fact that the middle abdominal segments are sculptured (Fig. 17E) instead of punctate as they are in *Hemicrepidius decoloratus*. The ninth abdominal segment is non-punctate on the dorsal disk in *Athous* sp. in contrast to the densely punctate condition found in this portion of the larvae of *Hemicrepidius decoloratus*. The sculpturing of the middle abdominal segments and the large size of these larvae are characteristics which set them off from all other genera of the tribe Lepturoidini in the Maine collection.

Little is known of these wireworms except that they are occasionally taken from beneath the bark of old apple trees and that they are not commonly found in the cultivated fields of the State.

### *Millepedes* -SOMETIMES MISTAKEN FOR WIREWORMS

The true wireworms of Harris (1862) are now generally known as millepedes (Plate IVE). While the word wireworm is

applied with validity to millepedes, for they are extremely hard bodied, elongate, wiry arthropods, its use in this capacity is often the cause of confusion. For it is now a common practice to designate the larvae of Elateridae as wireworms. Elaterid larvae differ quite markedly in certain characters of structure which serve to differentiate them from millepedes. Some contrasting characteristics are shown in Table 12.

TABLE 12  
*Contrasting Characters of Millepedes and Wireworms*

Millepedes	Elaterid larvae or wireworms
Many body segments	Three thoracic and ten abdominal segments
Two apparent pairs of legs to each body segment	Three pairs of anterior legs and a single median proleg at caudal end of body
Body curled up spirally when alarmed or resting	Body never curled up spirally
Color dark brown or black—never reddish brown	Color yellowish, light brown or shiny reddish brown
Graceful, flowing, wave-like movement on surfaces	Jerky, irregular movement on surfaces

In some New England localities millepedes are known as wireworms by certain persons while others in these same localities use the word as a designation for elaterid larvae only. In order to avoid confusion it appears logical to designate as wireworms only the young of the family Elateridae.

Millepedes are often reported as pests of vegetation in Maine. They attack newly planted seeds, especially corn, and also feed upon the roots of vegetables, corn, and flowers. During 1928, millepedes were very abundant in a field of corn at St. Albans, Maine. Heavy applications of barnyard manure had been made to this field in the spring preceding planting. Not much damage was done to the corn by the millepedes which were associated with numerous wireworms of the genus *Melanotus*. They are often found in flower beds where leaves and organic matter are allowed

to accumulate and decay. Millepedes sometimes attack potatoes in Maine. The holes made by them in potato tubers are larger and more superficial than is the injury ordinarily done by wireworms. Millepede injury to potatoes is well illustrated by MacLeod and Rawlins (1933, p. 7). They are not serious pests of potatoes in Maine according to our observations or available records and they are not generally considered of great importance as pests of other agricultural crops of the State.

#### THE ECOLOGY OF ELATERID LARVAE WITH ESPECIAL REFERENCE TO WIREWORM ABUNDANCE

Climate is probably an important factor in determining what species of wireworms shall inhabit Maine. According to Wardle (1929), "The complex of meteorological factors which constitute climate exerts a threefold influence upon insect life.

"In the first place, it determines the faunal components of a particular area, determines what types and what species of insects shall live in that area; in the second place, it determines the relative abundance of an insect species in an area; in the third place, it determines the seasonal incidence of the various stages in the insect life cycle, the period of the year when the insect shall be egg, larva, pupa, or imago."

The type of soil must also be important, for different species of wireworms are found in different types of soil.

Food is another important constituent of the wireworm habitat. In areas where the natural food of wireworms is destroyed by man, and cultivated crops are planted, the kind of crops grown determines to a large extent whether or not wireworms of certain species continue to live there. The extent that cultivation has changed our wireworm fauna is little known, but in some cases it has probably favored the abundance of certain species.

King, Arnason and Glen (1933, p. 15) say, "In connection with the protection afforded wireworms by their life in the soil, it is evident that the soil conditions found in cultivated fields are more favorable to the pest than those generally obtained in their original habitat, native prairie. This is certainly true as respects moisture conditions...." In Saskatchewan where they made

their observations, wireworm infestations are most severe where farming methods have provided sufficient moisture to support life. Injurious species of wireworms abundant there are different from those found in Maine, although certain agricultural practices here are likewise favorable to wireworm abundance.

The seasons determine the incidence of the stages of wireworms in Maine. The time of year for oviposition is approximately the same for all species for which the oviposition period is known. The pupation and emergence of the adult for all the species commonly found in the field occurs at approximately the same season. Egg laying of some common species occurs during late spring and early summer when the soil is warm and ample moisture is usually present. Pupation occurs during August and September and the beetles are formed early in the fall before cold weather sets in.

It is a well known fact that a certain amount of moisture is necessary to all insects. Wireworms have maximum and minimum moisture requirements, the limits of which are little known. According to Cameron (1913), larvae of *Agriotes lineatus* survived immersion in water for 6 days but failed to survive 8 days' immersion. In our laboratory, larvae of *Agriotes mancus* Say confined in pots failed to survive 3 days in saturated soil. Sixty of these larvae were placed in a large box in dry soil and given an opportunity to select soil of varying amounts of moisture. Their final location after 11 days is shown in Table 13.

TABLE 13  
*Moisture Reactions of Larvae of Agriotes mancus Say*

Date		Number of larvae located in			
Started	Examined	Dry soil	Moist soil	Wet soil	Saturated soil
12-20-28	1-8-29	3	37	17	0

Three larvae used in this experiment were unaccounted for. The soil used was air dried and water was added to the soil so that it ranged from saturated to air dry. Soil was considered moist if it

showed signs of being moist but did not stick together. Wet soil was so considered when it had absorbed sufficient moisture to stick together. The designation of saturated soil indicates soil which would absorb no more water. It would appear from this preliminary experiment that wet soil is preferred to either dry or saturated soil by the larvae of *Agriotes mancus*.

Larvae of *Agriotes mancus* Say and *Melanotus* sp. were placed in the soil of six-inch flower pots in order to test their reaction to moisture. Lantern globes were used to prevent escape of the larvae over the top of the pots. The soil was then wet with definite amounts of water so that conditions were maintained in the soil as indicated in the following table (Table 14).

TABLE 14

## Reaction of Elaterid Larvae to Soil Moisture in Pots

Date	No. of larvae	Species	Soil	Condition
9-20-31	40	<i>A. mancus</i>	Dry	All dead 11-10-31
9-20-31	40	<i>Melanotus</i> sp.	Dry	All dead 11-10-31
9-20-31	40	<i>Melanotus</i> sp.	Wet	37 alive 11-10-31
9-20-31	40	<i>A. mancus</i>	-Wet	All alive 11-10-31
9-20-31	40	<i>Melanotus</i> sp.	Saturated	All dead 11-7-31
9-20-31	40	<i>A. mancus</i>	Saturated	33 alive 11-10-31
12-8-34	40	<i>A. mancus</i>	Dry	All dead 12-9-34
12-8-34	40	<i>Melanotus</i> sp.	Dry	All dead 12-9-34
12-8-34	40	<i>Melanotus</i> sp.	Wet	All alive 12-19-34
12-8-34	40	<i>A. mancus</i>	Wet	All alive 12-19-34
12-8-34	40	<i>Melanotus</i> sp.	Saturated	1 alive 12-19-34
12-8-34	40	<i>A. mancus</i>	Saturated	15 alive 12-19-34

It would appear from Table 14 that wet soil is the most favorable to larvae of either *Agriotes mancus* or *Melanotus* sp. but that larvae of *Agriotes mancus* can live in saturated soil longer than those of *Melanotus* sp. Careful field observations along with these preliminary laboratory experiments lead us to conclude that soil which retains a large amount of moisture is the preferred habitat of wireworms, that dryness of the soil is fatal to them and that they can live in saturated soil for only a short time.

First instar larvae of *Agriotes mancus* exposed to the atmosphere in watch glasses in the laboratory were all dead within 18 hours. Eggs of *Agriotes mancus* Say which were similarly ex-

posed for an hour dried up and failed to hatch. Fifty per cent of newly laid eggs hatched when placed on the surface of moist soil in a sealed container.

Probably no wireworms perish in Maine because of lack of moisture. When the surface becomes too dry to support life it is possible for wireworms to migrate downward. The reverse of this happens during periods of excess moisture in case of *Agriotes mancus* larvae which come to the surface and find shelter beneath stones and debris. In the summer and fall when the soil becomes saturated, wireworms often enter tomatoes, muskmelons and even pumpkins lying on the soil surface. This does not happen when the soil surface is relatively dry. What happens to wireworms in nature during periods of abnormal rainfall is largely problematical. However, in an area at St. Albans, Maine, larvae of *Agriotes mancus* were very abundant during early spring in 1927 and after a period of rainy weather in which the area was inundated for approximately a week, none of the larvae could be found. They did not migrate to higher portions of the field and their disappearance could be accounted for only by their drowning.

TABLE 15

*Winter Habitat of Larvae of Agriotes mancus in Relation to Their Survival*

Date	No. of larvae	Depth taken in inches	Depth of frozen strata in inches	Condition of larvae
4-3-29	12	2	9-10	8 alive, 4 dead*
12-12-30	9	6 or less	0-6	Frozen, 7 dead
12-12-30	37	6 or more	0-6	Alive
12-12-30	5	1½	0-1	Alive†
12-12-33	3	9	0-9	Frozen, survived when thawed
4-21-33	15	4		14 alive, 1 dead‡
4-21-33	15	6		Alive†
4-21-33	7	6		Dead‡
3-21-34	9	Below 8 inch level	0-8	Alive
3-22-34	5	Just below 11 inch level	0-11	Alive
3-23-34	2	Just below 11 inch level	0-11	Frozen, survived when thawed
3-22-34	1	At 10 inch level	0-10	Frozen, survived when thawed
3-22-34	1	At 8 inch level	0-8	Died
3-30-34	2	At 2 inch level	0-2-	Alive
3-30-34	1	At 10 inch level	0-30	Dead

\* These larvae were taken from the thawed soil above a 9-10 inch frozen strata.

† These larvae were from fields in which the grass served as a protection for the soil against freezing.

‡ These larvae were all buried on October 17, 1932. It is significant that in the last case all 7 of the larvae died. These were larvae hatched in July of the previous year. All the others used were older larvae.

By cold hardiness is meant increased ability to withstand low temperatures. Sacharov (1930) found that cold hardiness of insects depends upon the minimum quantity of water and accumulation of fat in the organism. He says further that if the normal environmental conditions of insects are disturbed they are killed by cold weather whether they are prepared for it or not. Mail (1930, p. 590), speaking of wireworms, says, "As the soil cools they become dormant and a further drop in temperature after they become inactive finds them unable to escape. If cold weather at this time is severe and sufficiently prolonged, many of the wireworms will not survive." In spring when insects begin to lose their cold hardiness, a sudden cold snap or April blizzard is fatal to many of them according to Payne (1926).

A study of winter habitat of wireworms in Maine has been made. The data obtained are shown in Table 15.

Reference to the foregoing table shows that some wireworms are caught in the frozen soil. However, most of them migrate downward and spend the winter in the warmer soil beneath the frozen surface. Only 17 larvae out of 112 taken during freezing weather failed to survive and had these been thawed out under natural conditions in the soil some or all might have lived.

Removing wireworms from the soil and exposing them to freezing temperatures often kills them. Wireworms taken from the laboratory at a temperature of 23° C. and exposed outside for one hour where a temperature of -4.4° C. was fatal to the greater share of 25 larvae used in the test. A temperature of -12° C. killed wireworms exposed for one hour after having been taken from the soil. Wireworms kept in soil contained in flower pots in an outside insectary failed to survive the winter of 1929. Larvae of *Agriotes mancus* exposed to -25° C. for one hour in a constant-temperature chamber were all killed. Likewise a constant temperature of -20° C. for three hours was fatal to them, but an exposure for three hours of 10 larvae to a constant temperature of -3° C. was not fatal. Probably a temperature of -20° C. is never reached at the depth in the soil where most wireworms hibernate.

According to Mail (1930, p. 589), "Even as little as an inch and one-half of snow affords sufficient assurance that wireworms will survive a normal Minnesota winter." The greater number of wireworms migrate downward with cold weather. Some are

caught in the frozen strata by sudden freezing of the soil or extreme cold weather when the ground is bare of snow. Snow, grass, or other surface coverage acts as an insulation against deep freezing (Table 16).

TABLE 16  
*Conditions of the Soil Surface and Frost Penetration*

Date	Condition of soil previous to freezing	Inches of snow	Inches of frost
4-3-29	Potatoes 1928, plowed after potatoes were dug	0	9
12-12-30	Fall plowed grassland	2	6
12-12-30	Fall plowed grassland	2	6
12-12-30	Grassland	2	1½
12-12-33	Fall plowed grassland	4	9
12-12-33	Grassland	4	1½
3-21-34	Potatoes 1933, plowed after potatoes were dug	24	8
3-21-34	Grassland	18	6
3-21-34	Potatoes 1933, plowed after potatoes were dug	18	9
3-21-34	Grassland, grass cut and pastured afterward	4	18
3-30-34	Grassland, grass cut and pastured afterward	0	19
3-30-34	Grassland, grass cut and pastured afterward	12	2
3-30-34	Potatoes 1933, plowed after potatoes were dug	4	10
3-30-34	Grassland cut and pastured afterward	4	5
3-30-34	Grassland plowed in fall	6	8
3-30-34	Grassland	6	2
3-30-34	Soil unplowed after potatoes were dug 1933	0	30
3-30-34	Soil unplowed after potatoes were dug 1933	10	10
3-30-34	Grassland, grass cut used for pasture afterward	0	10
3-30-34	Grassland, grass cut used for pasture afterward	0	10

According to Cook (1930) weather data have been used to predict the outbreaks of the pale western cutworm. However, prediction of wireworm abundance based on weather data is very difficult because of the nature of the environment. Wireworms spend their life in the soil where they are not subject to the fluctuations of weather to which many insects are exposed. Wireworms migrate upward or downward with the season so that most of them escape extreme temperatures. In addition they are able to survive a certain amount of freezing. Possibly the effect of weather on parasites and predators of wireworms is important but the num-

ber of wireworms affected by parasites and predaceous enemies is relatively small. Parasitic nematodes of the adults of *Agriotes mancus* are occasionally abundant but in the past 8 years have not at any time completely overcome the wireworm population. Observations made yearly since 1926 indicate that weather conditions prevailing in Maine can not be depended upon to greatly diminish wireworm population. Weather conditions unfavorable to wireworms may cause a small fluctuation in numbers from time to time but certain crop and cultural practices are much more important in wireworm control.

### How WIREWORMS INJURE PLANTS

Potatoes are subject to injury by wireworms from the time the seed is planted until the crop is dug in the fall. Seed pieces planted in infested soil are often honeycombed by the tunnels of these insects. When the seed piece is injured too severely the plant does not develop. Plants from injured seed pieces may survive or not, depending upon the amount of injury to the seed and the persistence of the wireworms in following up the attack.

Wireworm injury to potato plants often occurs after the plants have attained some size (Plate V). The injuries consist of external scars and pits and occasional internal tunnels in the underground portion of the plants. The roots are also eaten by wireworms. Injury to the seed followed by attacks on the plants may cause a loss of the entire crop within certain badly infested areas.

The most serious wireworm damage done to potatoes on the whole is that done to the tubers after they are formed. Early in the season, feeding on the developing tubers results in pits and scars which may heal over and often cause misshapen potatoes (Plate VI). Late season injury by wireworms is likely to consist of well defined numerous pits, deep holes, and tunnels (Plate VII). Because of the depth of the tunnels and the longer period during which the insects may work, potatoes dug late in the season are subject to a greater amount of injury in wireworm infested soil than are those dug earlier.

Wireworms aid in disseminating diseases of potatoes. Dipterous larvae or maggots and other insects are often found in seed

pieces honeycombed by wireworms. Certain of these maggots were found to disseminate the blackleg disease of potatoes (Bonde, 1928 and 1930). The blackleg disease of potatoes is reported by von Hegyi (1909) to be associated with wireworm injury to the shoots. Pitting of potato tubers by wireworms was found to facilitate the entrance of the rhizoctonia fungus into potato tubers (Hawkins, 1928, p. 9).

There are certain injuries done to potatoes by other agencies which resemble very closely those done by wireworms. Rhizomes of quack grass, *Agropyron repens* Beauv., enter the tubers and when pulled out leave holes which resemble the newly made pits and tunnels of wireworms. However, in all cases examined where the rhizomes do not go entirely through the tuber the holes taper toward the interior (Plate VIII), while those made by wireworms are fully as large inside the tuber as at the entrance. When rhizomes of witch grass grow entirely through the tubers, the injury is similar to wireworm injury except that the holes are less sinuate than are those of wireworms (Plate IX). Fortunately for identification, rhizomes growing entirely through a tuber usually remain and the cause of the injury can be identified at once.

Dry core of potatoes caused by rhizoctonia disease makes a pit similar to that caused by wireworms (Barrus and Chupp, 1926). This sort of injury is shown in Plate X. Such injury could easily be mistaken for wireworm injury in which rhizoctonia had later become established, causing corky growths around the wireworm punctures. However, in tubers observed where wireworms were not present the rhizoctonia pits or pores were located principally at the lenticels (Plate X); whereas in wireworm attacks the pits may occur at any point on the surface of the tuber regardless of lenticels.

The wheat wireworm, *Agriotes mancus* Say, is the species of Elateridae which is most commonly injurious to potatoes in Maine. Wireworms of the genera *Melanotus*, *Ludius*, *Hemicrepidius*, and *Limonius* also attack potatoes and although all of these larvae are present in potato fields and feed upon potatoes, they are not usually abundant.

The corn grown in the State is subject to several forms of injury by wireworms, throughout the growing season. Germination of the seed is impaired by wireworms boring into the kernel (Plate XI A). Sometimes the inside is partially eaten away with-

out destroying the germ of the seed. Plants arising from such seed are weak and grow slowly or do not survive. Rotting of the seed often follows wireworm attacks and replanting is necessary. Succeeding plantings may also be destroyed. Older corn plants attacked by wireworms often take on a yellowish or reddish color and do not make a normal growth. This is because the roots are eaten away or the underground part of the stalk is attacked (Plate XI B). Feeding by wireworms on corn often starts early in the season from a small area of high wireworm concentration. As the season progresses and the plants within the infested area are destroyed the wireworms move outward in a widening circle. Roots of the larger plants are often attacked and destroyed so that the stalk is left without support and falls over. Ears of green corn which come in contact with the soil are sometimes infested by wireworms.

In one instance 132 larvae of *Agriotes mancus* were taken from within an area of one square foot around a stalk of corn. In cases where wireworms are numerous, large areas of corn are destroyed so that no crop is harvested from these places. Corn is grown extensively for canning in Maine. It is also grown for ensilage, forage, and grain. The damage caused by wireworms to corn grown for all of these purposes is considerable and wireworms probably damage corn in Maine more than do insects of any other kind.

Oats, wheat, barley, and rye are attacked by wireworms. Usually such attacks are not outwardly manifest, because of the large number of plants which grow within a given area. However, a few instances have been observed in which all the oat plants within a circumscribed area were destroyed by larvae of *Agriotes mancus* Say. Such injury was done to the underground portion of the stem rather than to the oat seed or roots.

The grasses, timothy and redtop are attacked by wireworms. It is rarely that the stand is entirely destroyed over a given area. However, it appears that wireworms may often be the cause of the so-called "running out" of meadows. Timothy being susceptible to wireworm attacks is injured by the larvae boring into the enlarged base or bulb of the plant. Such injured plants sometimes fail to survive the winter. The dying out of meadow grasses in-

jured by wireworms is often laid to winter killing, the true cause being unsuspected.

Cruciferous plants are damaged by wireworms feeding upon their roots. Cabbage and cauliflower are often injured, rutabagas are commonly pitted and scarred, and radishes are occasionally attacked.

Apples are affected by wireworms and the adult elaters. Larvae have been found boring beneath the bark of apple trees and inside fruit on the ground. Adult beetles of one species were discovered on apple trees during early spring and were feeding upon the swelling buds.

Data obtained from 1926 until the present time indicate that leguminous plants are as a group more resistant to wireworm attacks than are other groups of plants commonly grown within the State. Injury to peas has been observed to occur only rarely. Beans are occasionally attacked and in rare cases are injured, but on the whole they are relatively free from serious injury. In general, clover is free from wireworm infestation. Alsike clover has been observed to be affected by wireworms in a single instance where other food plants were absent. The immunity of red clover to attack by the larvae of *Agriotes mancus* Say was demonstrated in a series of tests conducted for the possible effect of the larvae on clover plants. In these tests clover was grown in six-inch flower pots, the holes in the bottom being plugged with plaster of Paris. Thirty wireworms introduced into each pot caused no apparent injury to the growing clover during two years time. Pots of soil in which potatoes were grown were used as checks, and in each of these were also placed 30 wireworms. The wireworms fed freely upon the potatoes and survived without great mortality. They also survived in the pots where the clover grew, although they were not so robust as they were where abundant food was available.

Tomato and egg plants are attacked by wireworms, probably the greater amount of injury being to fruit which comes in contact with the soil. Winter squash, pumpkin, muskmelon, and cucumber are among the Cucurbitaceae occasionally injured in Maine. A number of the ornamental flowering plants are sometimes attacked. Asters, phlox, gladiolus, and dahlia are sometimes severely damaged.

Wireworms feed on weeds and wild grasses. Quack grass, also called couch or quitch grass, *Agropyron repens*, is a favorite host of wireworms. This plant commonly grows as a weed in waste places, cultivated fields, and meadows. Barnyard grass, *Echinochloa crusgalli*, and foxtail grass, *Alopecurus* sp., are also hosts of wireworms. Common plantain, *Plantago major*, and dandelion, *Taraxacum officinale* L., were attacked by larvae of *Agriotes mancus* in a field where the corn had been previously destroyed by the larvae. Charlock, wild radish, and wild rutabaga are occasionally fed upon by wireworms. The destruction of weeds is important in the control of wireworms, for not only are they the food of the larvae but they furnish shelter during the mating season of the adults. Witch grass growing in old fields is attractive to wireworms and crops planted in such fields often are infested.

#### TAKING THE WIREWORM CENSUS WITH REFERENCE TO THE EFFECT OF NUMBER PRESENT AS AFFECTING VARIOUS CROPS

It is necessary to know the number of wireworms present in the soil as a basis for experimental work in their control. A knowledge of wireworm population is also essential for the arrangement of practical crop rotations to be used in wireworm infested soil. Different methods of taking soil samples in order to find the number of wireworms present have been devised. Lane (1928) described in detail a soil sifter of the shaker type. A soil washer was devised by Shirck (1930). Two screens were used by Rawlins (1934, p. 310) to separate wireworms from the soil.

Several methods have been tried by the writer for taking the wireworm census of the soil. It is important that the soil be dry enough so that it will not clog up the screen regardless of the method used in sifting. The simplest method used and in some ways the most satisfactory was that of sifting the wireworms from the soil by the use of a galvanized iron sieve with quarter inch screen. The soil was dug up and shaken through the sieve (Plate XII). Two men are expedient in this operation. One shakes the sieve and helps watch for the wireworms as they fall through. The other digs up the soil, places it in the sieve, watches for the wireworms as they pass through the sieve and records their number. It is a good plan to use a piece of dark colored canvas to sift the

soil on. The wireworms can be seen easily on the canvas and if for any reason it is thought necessary the soil can be resifted. Checks have shown that if the operators are careful a single operation is all that is necessary. The chief objection to this method is its slowness.

An old winnowing machine with screens of various sized mesh was used to shake wireworms out of the soil. While this was satisfactory from some standpoints, considerable time was required to clean the screen and to keep it in satisfactory operation. Washing the soil through screens of various sized mesh was also tried but this method required extra time in hauling the soil from the field to a water supply and was discarded as too time-consuming.

Finally a rotary ash screen was used and has since been a part of our experimental equipment (Fig. 18). This consists of a hopper and a galvanized iron screen cylinder of quarter inch mesh which can be rotated by means of a hand crank, the whole being placed on a wooden frame. The soil is placed in the hopper and runs through the rotating cylinder. The fine soil and wireworms drop through the screen and the coarser soil and stones or other debris go through and drop out of the opposite end of the cylinder. Two boxes are used to catch the soil, one being placed under the cylinder to catch the fine soil and wireworms and the other to catch the coarser debris. Three or four men can be used to advantage with the apparatus, making possible the sampling of a large area in a relatively short time. The method has proved to be the most satisfactory of several used. Securing the wireworm population before planting crops is done in the fall or during early spring. At this time tiny wireworms and eggs are not present. Sifting of wireworms from grassland necessitates the shaking out and tearing up of the sods previous to sifting. The use of hand labor is the only satisfactory method found of doing this.

The number and size of samples that should be taken involve many factors. From a practical standpoint it is best to start taking the census in areas likely to be heavily infested by wireworms. If wireworms are found in large numbers in such areas, samples can be taken then over a larger area, and so on, until the entire area to be planted is covered by a sufficient number of samples to establish the location and density of the wireworm population. In general the larger the number of samples that can be taken the better. Since

the process of securing accurate numbers of wireworms present in the soil requires considerable time, it is often necessary to be satisfied with a small number of samples. For this reason an understanding of wireworm ecology is desirable. In general, poorly drained areas are most heavily infested. Flat areas and surface depressions such as runs and basins should be sampled first. If these areas are heavily infested by wireworms other areas can then be sampled. Sometimes nearly the whole of a field is found to be occupied by wireworms and in such areas crops readily injured by these insects should not be planted. In other fields there may be one or two areas where wireworms are abundant and other areas where they are practically absent. Sometimes heavily infested areas can be avoided and crops susceptible to injury can be grown in those areas where wireworms are not abundant.

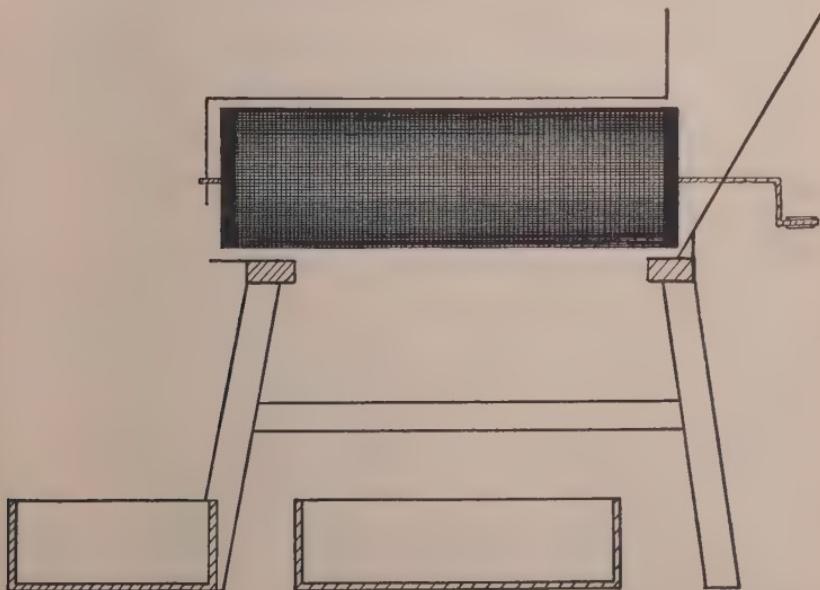


FIG. 18. A rotary sifter for removing wireworms from the soil.

Fifty-four samples of soil 9 square feet and 54 samples 30 square feet in area were taken during 1934 from experimental plots extending over  $1\frac{1}{2}$  acres. These soil samples were taken as

deep as wireworms could be found, most of the wireworms being above a 6-inch level, and none were below 8 inches. In some cases soil samples one square foot in area were taken for preliminary sampling to locate wireworm infestations. Probably these small samples, taken in larger numbers than it would be possible when larger ones are taken, are the best for all purposes, being more representative of the area than when larger ones are taken.

#### THE WIREWORM POPULATION IN RELATION TO POTATO INJURY

There is a general relationship between the number of wireworms in the soil and the injury caused by them to crops. Presumably a large wireworm population would be associated with a large amount of injury to crops growing in the infested soil. This is generally true, but there are exceptions which should be noted. The resistance of the crop grown, methods of cultivation employed, previous crops grown, the relative number of plants growing within a given area, the weather, parasites, and predators are all factors which may affect the amount of injury done by a given wireworm population.

According to Roebuck (1924) 200,000 wireworms per acre are regarded as the utmost limit for safety as regards damage to crops. He considers that 100,000 to 200,000 per acre will be tolerably safe for cereals, broadcast crops, established plants, or strongly spreading root crops. At 100,000 wireworms per acre he is of the opinion that little damage need be feared, and below 50,000 it is negligible.

The number of wireworms present in the soil has a direct bearing on the economical production of nearly all the major crops grown in Maine. However, since the potato crop is more severely injured by wireworms than other crops, the economic loss, on a percentage basis, caused to this crop, is annually greater than that caused to any other. Therefore, during the past six years we have given careful attention to the relationship of wireworm populations to the amount of injury caused to potatoes. It was assumed that as the wireworm populations became greater the amount of damage caused also increased and that at certain population densities the damage would be so great that potato growing would be

impracticable. With this assumption in mind a study was made of wireworm population in relation to injury done to potatoes, the ultimate object being to secure data by which growers could estimate chances of damage to potatoes when wireworms of various populations were present in the soil.

Soil samples were taken during spring in order to find out the wireworm population present. The potatoes were then examined after they were dug in the fall to find the extent of injury done to the tubers. An important factor in the injury caused to potato tubers by wireworms is the percentage of tubers injured. A study of the relation of various wireworm populations to the percentage of tubers injured has been made and the data are shown in Table 17 and Table 18.

Data obtained from 83 experimental plots (Table 17, Group 1) show that in 57 of the 83 plots not more than 10 per cent of the potatoes were injured, and in no case were more than 50 per cent of the tubers injured. The wireworm populations in this group ranged up to 14,700 per acre. In the second group of 43 plots, wireworm populations were present in numbers from 14,800 to 42,100 per acre. In 26 of the 43 plots, injury occurred to 30 per cent or less of the tubers. In the group as a whole, however, injury ranged up to 100 per cent. There were 104 plots considered in the third group, where the wireworm populations ranged from 42,200 to 532,000. In this group over 80 per cent of the crop was injured in 79 plots. Data for Table 17 are based on counts of the wireworms made during spring before the potatoes were planted and the percentage of injured tubers was obtained from counts of the tubers during the following September and early October.

The fall or spring previous to planting potatoes is the most practical time to take the wireworm census. This is especially true for those potato growers who wish to know the wireworm population of the soil before planting.

In order to save time, counts of wireworms and potatoes injured have also been made during the fall when the potatoes were dug. The relationship between the fall wireworm populations and percentage of tubers injured is shown in Table 18. This table shows the number of wireworms present in the fall but does not account for all the wireworms which were present during the grow-

ing season, for some were eliminated by pupation or other causes during the summer before the potatoes were dug.

TABLE 17

*Wireworm Springtime Population and  
Percentage of Injury to Potato Tubers  
in 230 Experimental Plots*

		Number of plots considered	Percentage of tubers injured
Wireworms per acre		0 to 14,700 inclusive	
49			0-5
8			6-10
5			11-15
6			16-20
Group	7		21-25
1	1		26-30
	1		31-35
	3		36-40
	2		41-45
	1		46-50
Total	83		
Wireworms per acre		14,800 to 42,100 inclusive	
1			0-5
5			6-10
6			11-15
2			16-20
6			21-25
Group	6		26-30
2	3		31-35
	4		36-40
	2		41-45
	1		51-55
	3		56-60
	1		71-75
	1		76-80
	2		100
Total	43		
Wireworms per acre		42,200 to 532,000 inclusive	
2			26-30
1			31-35
2			41-45
3			46-50
Group	3		51-55
3	2		61-65
	6		66-70
	3		71-75
	3		76-80
	10		81-85
	7		86-90
	13		91-95
	49		96-100
Total	104		

TABLE 18

Fall Wireworm Populations in Relation to Percentage of Potato Tubers Injured

<i>X</i> = Wireworm Populations in Thousands Per Acre	<i>Y</i> = Percentage of Tubers Injured																				
	0.0-50	51-100	101-150	151-200	201-250	251-300	301-350	351-400	401-450	451-500	501-550	551-600	601-650	651-700	701-750	751-800	801-850	851-900	901-950	951-1000	
.0-10	45	11	5	5	8	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	82
11-20	44	4	5	3	4	5				2										29	
21-30	11	4	1	1		2	1	1	1	1	1	1	1	1	1	1	1	1	1	14	
31-40					2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	13	
41-50										1	1	1	1	1	1	1	1	1	1	6	
51-60						1					22								1	6	
61-70																		1	3	7	
71-80																		2	2	5	
81-90																		1	2	5	
91-100											2	1	1	1	1	1	1	1	3	7	
101-110											1	1	1	1	1	1	1	1	3	6	
111-120													2					1	2	5	
121-130																		1	3	5	
131-140											1							4	6		
141-150											1							1	2	4	
151-160												1		22				1	6		
161-170																		1	2		
171-180																			1	3	
181-190																			1		
191-200																					
201-210																					
211-220																		1	2	3	
221-230																		1	2	3	
231-240																		1			
241-250																		1			
251-up																		2	16	9	

Total number = 227

Mean *X* =  $6.269 \pm .314$

Mean *Y* =  $10.357 \pm .356$

S.D. *X* =  $7.024 \pm .222$

S.D. *Y* =  $7.951 \pm .252$

Table 18 shows that wireworm populations ranging up to 10,000 per acre caused up to 5 per cent of the tubers to be injured in 45 out of 82 plots. At higher populations the trend is generally upward, and at populations of from 91,000 to 100,000 per acre 3 out of 7 plots show injury from 95.1 to 100 per cent of the tubers.

There is approximately 45 per cent decrease in wireworm populations in cultivated fields from spring to fall. This decrease should be taken into account in making a comparison of injury caused by wireworm populations shown in Tables 17 and 18. That

TABLE 19

*Fall Wireworm Population and Number of Punctures in Potato Tubers in 140 Experimental Plots*

Number of plots considered		Punctures per 100 tubers
<b>Wireworms per acre 0 to 10,000 inclusive</b>		
Group	15	0-50
1	2	51-100
	11	101-200
	6	201-400
Total	34	
<b>Wireworms per acre 11,000 to 30,000 inclusive</b>		
Group	1	0-50
	5	51-100
	4	200-400
2	1	500-600
	1	700-800
	1	900-1,000
	1	1,100-1,200
Total	14	
<b>Wireworms per acre 31,000 to 468,000 inclusive</b>		
Group	3	101-200
	5	300-400
	10	500-600
	17	700-800
	9	900-1,000
	9	1,100-1,200
	1	1,300-1,400
	6	1,500-1,600
	10	1,700-1,800
	10	1,900-2,000
	5	2,100-2,200
	1	2,300-2,400
	5	2,500-2,600
	1	3,700
Total	92	

Wireworm populations considered in this table are those present at the time when the potatoes were harvested during September and October.

is, 82 per cent should be added to the populations of Table 18 to approximate those represented in Table 17.

The extent of injury caused to individual potatoes must be considered in evaluating damage caused to the potato crop by wireworms. The number of punctures per tuber is an index to the damage done. It also serves the purpose from the standpoint of marketing, for if tubers are badly punctured they are not readily sold as first-class on the market. However, the interior injury

TABLE 20

*Wireworm Populations in Relation to Punctures Caused to Potato Tubers*

<i>X = Wireworm Populations in Thousands Per Acre</i>	<i>Y = Wireworm Punctures Per Tuber</i>														<i>Total Number = 141</i>											
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160	161-170	171-180	181-190	191-200	201-210	211-220	221-230	231-240	241-250	251-Up
0-10	224	241																								33
11-20	141	121	1																							12
21-30	1																									3
31-40				1113	1																				10	
41-50					211																				5	
51-60						21	1	1																	6	
61-70							2	1121																	7	
71-80								21																		5
81-90									1																	5
91-100										1																6
101-110											11															6
111-120												1														5
121-130													1													5
131-140														1												5
141-150															1											4
151-160																1										6
161-170																	1									3
171-180																		1								2
181-190																			1							1
191-200																										
201-210																										
211-220																										
221-230																										
231-240																										
241-250																										
251-Up																										

$$\text{Mean } X = 8.369 \pm .404$$

$$S.D. X = 7.115 \pm .286$$

$$\text{Mean } Y = 9.929 \pm .434$$

$$S.D. Y = 7.647 \pm .307$$

caused is not always indicated by the number of punctures per tuber. In order to be sure of the extent of damage it is sometimes necessary to cut open the tubers and examine them. Unfortunately this cannot be done on an extensive scale and so the number of punctures per tuber remains the best practical measure for judging damage caused by wireworms to individual potato tubers.

Seventeen out of 34 plots, containing wireworms up to 10,000 per acre, contained from 50 to 100 punctures per 100 tubers (Table 19). Since this would be one puncture or less per tuber, such injury would not ordinarily be serious, especially since not more than 50 per cent. and probably considerably less, of the potatoes would be punctured at all. Even wireworm populations up to 30,000 per acre do not cause an excessive number of punctures per tuber except in relatively few cases. At populations above 30,000 wireworms per acre the percentage of cases where there are 9 or more punctures per tuber is relatively high.

Table 20 includes data arranged to show the distribution of cases and variation of the number of punctures per tuber in relation to various fall wireworm populations.

It will be noticed in Table 20 that there are certain inconsistencies between wireworm population and the number of punctures per tuber, but in general there is an upward trend of the number of cases of a relatively high number of punctures per tuber with the increase in wireworm populations.

In order to obtain information upon the possible relationship between the wireworm population, the percentage of tubers injured and the number of punctures caused, data were obtained from 55 plots, each containing 30 square feet. These data were obtained during the fall of 1934 and are shown in Table 21.

The rise in the percentage of tubers injured is consistent with the rise in wireworm population. However, there is not always an increase in the number of punctures per tuber consistent with increase in wireworm population, as is shown by reference to Table 21. There is an average of 212.4 punctures per 25 tubers in the sixth group and an average of but 169.5 per 25 tubers in the seventh group, although there were less wireworms per plot in the sixth group than in the seventh.

Market standards and prices of potatoes vary from locality to locality and from year to year. There are also variations in the

TABLE 21

*The Relation of Fall Population of Wireworms, the Percentage of Tubers Injured and the Number of Punctures Caused*

Number of wireworms per plot 30 sq. ft.		Percentage of tubers injured	Average percentage of tubers injured	Punctures per 25 tubers	Average number of punctures per 25 tubers
Group 1	0	25.5	15.9	11	22.5
	0	16.2		31	
	0	20.0		11	
	0	5.8		24	
	1	8.8		7	
	1	19.1		51	
Group 2	5	42.4	38.6	9	40.3
	5	32.6		38	
	6	50.0		7	
	7	34.7		61	
	10	30.7		101	
	10	21.9		32	
Group 3	11	58.1	50.0	34	63.7
	13	52.7		10	
	14	42.5		31	
	14	44.7		102	
	14	57.1		106	
	14	22.0		5	
Group 4	14	54.0	69.7	46	147.5
	19	76.9		145	
	23	75.0		92	
	27	69.1		133	
	28	26.3		137	
	31	93.0		157	
Group 5	33	81.8	80.3	193	210.0
	36	69.7		54	
	36	73.4		173	
	37	69.5		241	
	41	72.0		158	
	43	90.6		309	
Group 6	46	100.0	84.8	183	212.4
	47	88.8		228	
	49	89.7		214	
	49	93.7		158	
	49	90.4		220	
	60	84.3		94	
Group 7	61	92.5	91.0	241	169.5
	62	79.1		212	
	65	68.0		50	
	73	94.8		378	
	76	76.3		160	
	76	98.2		428	
Group 8	77	85.0	93.5	136	412.4
	80	85.7		63	
	88	93.7		316	
	94	84.5		55	
	94	100.0		244	
	100	94.2		303	
Group 9	109	88.6		292	
	109	85.7		395	
	110	91.4		421	
	110	92.6		573	
	115	97.7		424	
Group 10	120	97.5		413	
	159	100.0		478	

amount of injury which a given population of wireworms may cause. Consequently it is impossible to predict the exact wireworm populations which would cause commercial injury to potatoes. However, the potato branding law now in effect in Maine permits not more than a 5 per cent loss because of wireworms or other insect injury to potatoes branded as U. S. No. 1 and potatoes so branded must not have their appearance materially altered by injuries. Each grower should consider the matter and decide for himself what his chances are of successfully marketing potatoes grown in wireworm infested soil. The tables and preceding discussion of the subject are offered as a guide to what injury is to be expected from wireworms of various populations. This can be consulted with some confidence, because the subject has been studied experimentally over a period of six years and general observations for nine years have borne out the data recorded in Tables 17 to 21.

#### CULTIVATION AS A MEANS OF CONTROLLING WIREWORMS

The exact nature of the original habitat of certain species of elaterid larvae is practically unknown. Before the soil was cultivated our native species must have lived on wild plants. With the coming of agriculture and cultivation of the soil the natural habitat of wireworms was changed. Cultivated crops were substituted for the wild food plants of wireworms and in many cases an environment favorable to wireworm abundance has been maintained. Large wireworm populations build up in soils favorable to wireworm incidence when they are planted to hay crops such as timothy and redtop. If these crops are left to stand un molested for a period of years the wireworm populations may become very great. Then when the grass is plowed up and hill or row crops are planted they are often destroyed or badly damaged by the wireworms present. Reported wireworm outbreaks are often merely the destruction of a row or hill crop succeeding hay crops. The success of many of the cultural practices used in control of wireworms depends upon changing the soil environment from one favorable to wireworm abundance to one which is unfavorable.

It is entirely possible that cultivation of certain types or at certain seasons of the year may serve to make environmental condi-

tions of the soil favorable to wireworm depredations. For instance, in the dry farming area of the Great Basin of the Pacific Northwest, spring harrowing loosens up the soil and allows the wireworms more easy access to the plant stems (Lane, 1931, p. 8). In Saskatchewan the heaviest wireworm infestations are, on the whole, associated with fields which have been under cultivations continuously (King, 1928, p. 699) and the severity of damage to the first wheat crop after the year of summer fallow seems to be largely the result of soil moisture conditions favoring wireworm activity for a longer time than in other fields. Nevertheless, summer tillage is recommended for Saskatchewan in order to destroy weeds which would furnish food for wireworms (King, Arnason and Glen, 1933, p. 9).

Cultivation as a method of wireworm control has been recommended in the United States and Canada. Hyslop (1916, p. 4) regards deep cultivation as desirable in corn land infested by the wheat wireworm, *Agriotes mancus* Say, and thorough tilling after the crop has been removed. Strickland (1927, p. 17) found that frequent cultivation during spring and early summer in Alberta, Canada, exposed many wireworms, in all stages of development, to the attacks of birds. In New York, Rawlins (1934, pp. 312-314) shows that there is a decrease in the wireworm population in cultivated soil.

Speaking of the results of certain experiments in wireworm control in Maine during 1911, Johannsen (1912, p. 462) says: "There is nothing, however, in the experiments in 1912 to invalidate the conviction that continued cultivation and rotation of crops will in the course of several seasons materially reduce the wireworms in an infested field."

Beetles of *Agriotes mancus* Say are known to leave fields during the period of their cultivation. Gravid females of this species have been observed in the act of leaving cultivated fields and others were caught on sticky surfaces on screens erected nearby. Some eggs are laid in cultivated fields, and some of these hatch, for young wireworms from the current year's eggs are occasionally found there, but it appears likely that most of the female adults of our commonly destructive wireworms leave tilled land before ovipositing. Eggs of *Agriotes mancus* Say, *Cryptohypnus abbreviatus* Say, and *Melanotus* sp. were found to be desiccated on exposure to

the atmosphere while on the surface of soil. It is probable that a portion of the eggs do not hatch when they are exposed to the atmosphere by being thrown out on the surface during cultivation. There are relatively few wireworms of new generations which arise in cleanly cultivated fields, and once the initial infestation is eliminated reinestation rarely occurs until the soil is no longer cultivated. A few wireworms are crushed or otherwise destroyed by farming operations such as plowing, cultivating, or harvesting; however, this number must be small, for close observations of infested fields during several years have disclosed less than a dozen wireworms so killed. Cultivation does not occur at the time of year when pupae and adults are present in the pupal cells and so these stages are not affected by cultural practices in Maine. Probably the greater part of the elimination of wireworms from cultivated fields can be attributed to their transformation to pupae and their emergence as adults. Since the number of pupae and adults that can be found in the soil does not entirely account for the large percentage of wireworms eliminated, there is a discrepancy which can only be attributed to other causes, such as their destruction by mechanical processes of cultivation, elimination by parasitic and predaceous enemies, unfavorable weather conditions and possibly other factors.

Lane (1931, p. 6) recommends absolutely clean summer fallowing and emphasizes the value of the starvation of wireworms and the maintenance of dry conditions of the soil, through summer fallowing, as a measure against first year larvae of the dry land wireworm. Numerous observations of wireworm infested fields, in Maine, have shown that new generations of wireworms do not occur to any extent in cleanly cultivated fields. On the other hand, the only instance of continuous wireworm infestation observed to occur in cultivated soil was in a potato field where quack grass or quitch grass, *Agropyron repens*, grew in great abundance. A heavy coverage of grass and weeds in this field very closely simulated conditions in uncultivated land. Certain weeds, *Brassica arvensis* L., wild mustard, charlock or field kale as it is sometimes called, and *Brassica campestris* L., wild rutabaga, are notably favorite food plants of wireworms in Maine. These insects are known sometimes to prefer *Brassica arvensis* and *Brassica campestris* to corn. In corn fields where these weeds are destroyed, wireworms

are sometimes found to transfer their attack to the corn plants which had before remained uninfested. Many weeds serve as hosts of wireworms (see list of food plants, p. 6). Witch grass, *Agropyron repens* L., is freely eaten and its growth in cultivated fields may greatly favor wireworms. When crops are destroyed and no other food is available, a variety of weeds may be eaten which are not attacked by wireworms under ordinary circumstances.

It has been thought by many of those in close contact with the problem of wireworm injury to Maine crops, that continuous cultivation was effective in reducing wireworm populations of the soil. Such ideas as there were on the subject came as a result of observation by investigators and of the experiences of farmers. Up to 1926, farmers in Maine were not generally using cultivation as a means of reducing wireworm injuries to crops, although certain farmers who had been raising potatoes as often as possible in their crop rotation were having little trouble with wireworms.

TABLE 22

*Reduction in Populations of Larvae of the Wheat Wire-worm, *Agriotes mancus* Say, in Cultivated Soil  
(Fall Counts)*

Population in thousands per acre		
1931	1932	1933
120	92	19
170	73	17
225	178	63
212	127	15
532	107	20
416	88	18
329	133	18
246	96	11
93	35	5
43	29	.8
132	114	111
253	124	19
467	148	112
273	103	23
151	165	51
162	119	78
48	25	40
Totals	3872	1755
Averages	227.76	108.2
Percentage decrease		54.7
		628
		86.9
		83.8

Because there were so little data on reductions of wireworm populations due to cultivation, work on securing information on this subject was begun in 1931. The object of these investigations was to obtain information on the effect of each year of cultivation on the number of wireworms present in the soil. Seventeen plots, each 27 by 30 feet, were used. The wireworm census was taken each fall. Data obtained on the effect of each of three years of cultivation of the soil on the wireworm population are shown in the following table (Table 22).

There was an average accumulation of 156,560 per acre in plots which remained uncultivated for 3 years, an increase of 168 per cent. This area consisted of 44 plots extending over approximately 1½ acres. These were check plots in the same field as the 17 in the foregoing table.

The reduction of wireworm population from spring to fall in cultivated experimental plots is shown in Table 23.

TABLE 23

*Reduction in Wireworm Populations in Soil Planted  
to Potatoes during 1934*

Spring	Wireworms per square yard	Fall	Percentage decrease in wireworms during the season
21		8	62.0
13		10	24.0
31		19	38.8
46		28	59.2
51		31	59.3
32		15	53.8
54		24	55.6
26		13	50.0
31		20	35.5

A summary of the reductions of wireworm populations is shown in Table 24.

When considering reductions in wireworm populations which are likely to occur because of cultivation of the soil, the size of the wireworms present in the beginning is important. If larvae of *Agriotes mancus* which are  $\frac{3}{8}$  of an inch or less in length are found during the fall they are of the current year's growth and will be

TABLE 24

*Summary of Reduction in Population of the Wheat  
Wireworm, *Agriotes mancus* Say, in all  
Cultivated Plots*

Spring of first year to fall of first year	Fall of first year to fall of second year	Fall of second year to fall of third year
Percentage of Reduction		
45.5	65.1	80.2

present the next summer and until August of the second year and a few usually live over even until August of the third summer.

That cultivation is an effective method of reducing wireworm populations is borne out both by experimental data and observations. During eight years of close contact with the problem of wireworm infestation in Maine, none have been found which could not be eliminated by clean, thorough, and consecutive cultivation. A three-year period of clean cultivation is sufficient to reduce the wireworm population to harmless proportions unless it is very great in the beginning. Four years may be required to make the soil safe for the growing of potatoes where wireworms were exceedingly abundant in the beginning.

Clean cultivation of the soil is a practical control measure for wireworms. No expensive materials or additional machinery are required to put this control method into effect and in addition it has the advantage of also being a good general field practice.

#### THE EFFECT OF SUMMER FALLOW ON THE WIREWORM POPULATION

Farmers are advised by Comstock and Slingerland (1891, p. 213) not to lose the use of their land for a season and the labor necessary to keep it free from vegetation with the hope that wireworms may be starved in fallow soil. In Northwestern United States, Lane (1931, p. 6) found that wireworms were worse in fields where summer fallow was carried on the year before planting. Fallowing is said to conserve moisture so that wireworms

can live in this region. Lane suggests that if summer fallow is kept entirely clean and well cultivated it will act against wireworms, as their only available food supply would be destroyed and first year wireworms could not survive.

In our laboratory, wireworms one and two years old kept in pots of soil free from vegetation have survived a summer season. They have also survived a year in pots in which red clover grew, although the clover was not apparently fed upon by the wireworms.

A quarter acre plot where the wireworm population numbered approximately 48,000 per acre was kept cleanly fallow during the summer of 1928. Approximately one-third of the wireworms present at the initiation of the experiment had disappeared by July 1. Since pupation had not yet occurred, the disappearance had to be accounted for otherwise. It was found that wireworm populations had become larger in the margins of plots immediately surrounding the fallow plot. The population in the fallow plot also remained most nearly stationary toward the center of the plot. This indicated that there was some migration from the fallow plot to the margin of cultivated plots where crops were growing. However, crops planted the year following were damaged approximately as much on the fallow plot as on plots where cultivated crops grew the previous year. Examination of several fields kept fallow during the summer has not shown a reduction in wireworm populations consistent with the expense involved. Such data as we have obtained indicate that the raising of a cultivated crop is about as efficient a method in reducing the wireworm population as is summer fallow.

#### THE EFFECT OF FALL PLOWING UPON WIREWORMS

A difference of opinion in regard to the effect of fall plowing upon wireworms has been expressed by entomologists. Comstock and Slingerland (1891, p. 245) were convinced that fall plowing is more valuable for control of the adults than for destruction of the larvae. Forbes (1892, p. 42) also expresses the opinion that in Illinois the greatest value of fall plowing consisted of its effect on adults. Graf (1914, p. 64) says, "Plowing in the fall is a fair remedy against the pupae, but at that time of year the soil is dry

in Southern California and is turned up in large clods; consequently many pupae escape destruction." O'Kane (1913, p. 4) expresses the opinion that if sod ground is plowed late in the fall many of the wireworms will be turned up and exposed to the winter weather or to birds, and will not survive and that such plowing will be more effective if done late, after the worms have grown sluggish. Strickland (1927, p. 17) concludes that late fall plowing is of little value in connection with *Ludius aereipennis*. Johannsen and Patch (1911, p. 230, 231) found that fall plowing did not prevent a heavy infestation of a field of sweet corn by wireworms. This field was plowed during the autumn preceding the planting of the sweet corn.

Pupae, adults, and larvae of Elateridae are possibly affected by fall plowing. The older larvae and mature adults are undoubtedly the most resistant to injury. Eggs are laid in June and July for the most part and so would not be affected by plowing during fall after crops are removed. The young larvae grow slowly and are very small by fall of their first year. They are sensitive to an unnatural habitat as is evident when they are kept in salve boxes or are exposed on the surface of the soil. Little is known of the effect of plowing upon first-year larvae. The older larvae of *Agriotes mancus* Say are very active and soon bury themselves in loose soil when exposed on the surface. Pupae are relatively delicate and much more susceptible to crushing than the adults or older wireworms, but when the pupae are broken from their cells they do not always die (Table 25).

From Table 25 it will be seen that pupae are able to develop when broken from pupal cells. It would appear that some of the

TABLE 25

*Pupae of Agriotes mancus Say Broken from Their  
Pupal Cells*

Number	Date taken	Adult emerged	Final disposal
1	8-22-31	8-26-31	Discarded 12-12-31
23	8-6-28	8-10-28 to 8-21-28	18 of 23 developed
2	2-27-31	3-4-31	Alive 4-27-31
5	8-7-33	9-17-33 to 9-21-33	Died 9-1-34

pupae present in the soil might survive the effect of plowing even where it is possible to plow during early August, at the time when the majority are in the pupal stage. It must also be considered that only a portion of the wireworms pupate each year, that the pupae do not injure plants and that those wireworms which had not yet pupated would not be seriously injured through the plowing of the soil.

Fall plowing has been recommended on the basis that it affects the adults adversely. Conclusions based on certain experiments show that adults broken from the pupal cells perish (Comstock and Slingerland, 1891, p. 245, 246). Their experiments were based upon adults reared under somewhat unnatural conditions. Our experiments in which the beetles were broken from their pupal cells in the field and placed on moist soil similar to that found in freshly plowed soil have shown that many are able to survive for several months. On March 8, 1934, several beetles were still alive although removed from the pupal cells in the soil the previous September. Only a portion of the elaterid population is in the beetle stage during fall and some of these may not be broken out of their pupal cells when the soil is plowed, especially if large sods or clods are turned up. A few beetles may be injured by the mechanical action of plowing and some may be turned out to be eaten by predaceous enemies.

It is in the larval stage that Elateridae damage crops directly and it is therefore most desirable that the larvae be destroyed. When larvae are in their second and third years they are not greatly affected by the mechanical action of plowing. Very young larvae are more tender than the older ones, but all the larvae are very active and they burrow into the soil almost immediately after exposure. It is necessary for any predaceous enemy to follow the plow very closely in order to catch the wireworms which are plowed out. A sparrow was observed to catch wireworms exposed by plowing. Blackbirds also follow the plow and pick up occasional wireworms. However, the greatest value of birds in wireworm control is probably in their destruction of the adult beetles (Thomas, 1931, p. 160). A few larvae have been found crushed or otherwise injured by the plow but such cases represent but a small portion of the total population.

The depth of freezing is influenced by plowing. One, two, and three year old larvae of the Great Basin wireworm, *Ludius pruininus* Horn, spend the winter deep enough in the soil to avoid freezing, according to Lane (1931, p. 5). McColloch, Hayes, and Bryson (1927, p. 563) found the average depth of wireworms in the soil to be 7.7 and 10.1 inches for the winters of 1922-1923 and 1925-1926 respectively. They found wireworms above a depth of 6 inches in midwinter, that is, in a location where they would have to endure much greater cold than individuals which penetrated the soil to greater depths. Ford (1917, p. 102) reports that: "The usual depth at which these wireworms, *Agriotes obscurus*, are found in the soil varies from one inch in pasture to eight or nine inches in potato fields." In winter they bury themselves much deeper, and were found at a depth of as much as two feet.

Mail (1930, p. 590) says: "In summer when the larvae are active they can go down to escape fatal high temperatures, but as the soil cools they become dormant and a further drop in temperature after they become inactive finds them unable to escape. If the cold weather at this time is severe and sufficiently prolonged many of the wireworms will not survive."

Preliminary data on this subject have been obtained and are summarized in the following table.

Potatoes were grown in Plot 1 in 1928 and the soil was plowed in the fall of 1928. Grass grew in Plot 2 in 1929 and the soil was

TABLE 26

*The Winter Habitat of Elaterid Larvae*

Plot number	Date	Inches snow	Inches frozen soil	Depth of wireworms in inches	Number and condition of larvae found
1	4-3-29	0	9	2	Eight alive, 4 dead
2	12-12-30	2	6	Less than 6	Nine all frozen, 7 did not survive
3	12-12-30	2	6	More than 6	Thirty-seven, all alive
4	12-12-30	2	1	1½	Five larvae alive
5	12-12-33	4	9	9½	Three larvae alive
6	12-12-33	4	1½	2	Seven larvae, all alive
7	3-31-34	24	8	7½ — 12	Nine larvae, all alive One in frozen soil
8	3-30-34	12	2	2½	Two larvae alive
9	3-30-34	0	30	10 — 12	One larva ( <i>H. decoloratus</i> ?) dead

plowed in the fall of 1929. As nearly as could be determined the conditions in Plot 3 were the same as those in Plot 2. Plot 4 was in unplowed grassland. Plot 5 was plowed from sod during the previous fall. Plot 6 was of unplowed grassland. Plot 7 was in fall plowed land where potatoes were previously grown during summer. Plot 8 was in grass which was cut for hay and pastured afterward. Plot 9 was in soil planted to potatoes in 1933, and was not plowed in the fall after the potatoes were dug.

Available data indicate that the soil freezes to a greater depth in plowed grassland than it does in unplowed grassland, other things being equal. However, snow coverage must be taken into consideration. Larvae of *Agriotes mancus* were found deeper in plowed grassland on December 12 in 1930 and 1933 than they were in unplowed grassland. It appears that these larvae are not always killed, although caught in the first six inches of plowed soil during winter. Older larvae buried in unplowed grassland at a depth of 6 inches survived winter temperatures to the extent of 96.7 per cent of their number during 1933, while all the young larvae kept under the same conditions perished. Plowing in the fall is not entirely effective as a control measure against wireworms in Maine. Probably no great damage is done to the adult beetles by fall plowing, and moreover there is but a small percentage of the total elaterid population to be found as adult beetles in the soil at this season of the year. Mechanical injury and exposure of larvae to natural enemies by fall plowing affect but a portion of the wireworms in the soil. Since wireworms often attack crops planted in soil which was plowed during the previous autumn, it is evident that fall plowing is not an entirely effective method of wireworm control. It is probable that the greatest value of fall plowing is not that great numbers of the wireworms are directly destroyed by the mechanical action of plowing but rather that their environment is suddenly changed and conditions unfavorable to their successful hibernation are set up. That is, the soil freezes deeper, and freezing and thawing occurs so that wireworms are subject to greater changes of temperature in fall plowed soil than in unplowed soil. Data on this point while suggestive of lines desirable for future research are of a preliminary nature only.

### THE EFFECT OF FERTILIZER ON WIREWORMS

The effect of fertilizer on wireworms has often been discussed in the literature of economic entomology by Hyslop (1916, p. 5), Treherne (1923, p. 4), Thomas (1930, p. 39), and others. The judicious use of commercial fertilizer and barnyard manure enabled a certain field of corn in Central Maine to withstand the attack of wireworms (Hawkins, 1928, p. 13, 14).

The opinion found in the literature regarding the value of fertilizer for wireworm control appears to be based mostly on field observations. Consequently, a series of plots were laid out in 1932 to test the effect of fertilizer on wireworms. The soil of these plots was infested and potatoes grown there the previous season were badly injured. The plots were all of as nearly the same type of soil as it was possible to find and all had received the same treatment in regard to cultivation and fertilizer previous to the initiation of the study. The soil was plowed during the fall and harrowed during spring and potatoes were then planted in all the plots. Commercial fertilizer (5-8-7) was used on one half of the plots and the rest were left unfertilized. Each plot was 30 by 27 feet.

The potatoes came up in all the plots and the only difference to be noted at first was that some of the potato plants in the unfertilized plots were spindling and not so healthy looking as in the plots where fertilizer was used. After a time the absence of plants was noticed and examination showed that certain plants had failed to survive. Wireworms were responsible in part for killing some of the plants.

The potato tubers harvested from unfertilized plots were small and knotty. Although the average number of injuries per tuber varied but slightly from that of tubers in the fertilizer plots (Table 27) the injury was relatively greater because of the small size of the tubers in unfertilized soil.

The average infestation was somewhat greater in the unfertilized plots than in the fertilized plots and the percentage of injured tubers in unfertilized soil was somewhat smaller than in those fertilized. In general the data in Table 27 indicate little difference between the amount of injury to potatoes grown in fertilized soil as contrasted with those grown in unfertilized soil. The

TABLE 27

*Wireworm Injury to Potatoes in Fertilized and Unfertilized Soil*

Number of larvae	Number of tubers per plot	Number of tubers injured per plot	Average number of punctures per tuber
Unfertilized Soil			
101	96	96	6.0
170	121	121	12.4
94	101	101	8.5
254	176	176	17.0
290	109	99	21.5
157	88	66	8.7
271	97	89	10.6
73	73	39	4.7
Total 1410	861	787	89.4
Fertilized Soil			
330	190	190	13.6
58	127	85	4.2
153	93	93	5.5
192	108	108	7.5
204	143	143	12.2
132	126	102	15.0
140	96	80	20.0
75	101	98	12.0
Total 1284	984	899	90.0
Summary of Averages			
Fertilized 160.5	123.0	112.4	11.25
Unfertilized 176.2	107.6	98.4	11.17

main value of fertilizer in relation to the effect of wireworms on potatoes is in producing vigorous growth. Incidentally the yield is better where the soil is fertilized. Fertilizer has no apparent effect in preventing wireworm injury to the tubers after they are formed in the soil.

## THE EFFECT OF DRAINAGE ON WIREWORMS

Drainage is generally recommended as a good method of combating wireworms, according to Fitch (1867, p. 540), Pettit (1910), Hyslop (1916, p. 6), and Metcalf and Flint (1928). General observations in Maine have shown that wireworms of certain species inhabit relatively moist, poorly drained soil. On the other hand there is at least one species which inhabits well drained soil.

Drainage is very useful in that it makes the soil easy to till and tillage breaks up the old sods, grass and weeds so that the soil is no longer a suitable habitation for wireworms. An instance of drainage being used effectively against the wheat wireworm is recorded from Maine (Hawkins, 1928, p. 14). On the other hand there is a record of continual infestation in another locality by this species in drained land. That is, whenever this drained area is seeded to grass and allowed to stand for a few years, wireworms are always present, although they are probably not so abundant here as they were before the drainage system was installed. This field has been under yearly observation since 1928. The soil in this area is of a heavy clay loam and underground drainage causes it to dry out sooner than surrounding undrained soil. When the field is prepared for crops, the drainage system can be traced by the relative dryness of the soil adjacent to it. It should be stated, however, that wireworms are never very abundant near the drain. During the spring of 1934, for instance, the infestation ranged from 6 to 9 per square yard in the vicinity of the drains as compared to from 8 to 69 per square yard in undrained soil of the same type. Limited observations indicate that drainage is an aid in control of the wheat wireworm. The chief value of soil drainage in wireworm control is that the land is made dry enough so that it can be thoroughly cultivated and thereby the wireworms living there are controlled. Needless to say, a wireworm of the genus *Limonius* which lives in dry sandy soil is not affected by drainage.

#### LAND UTILIZATION TO AVOID WIREWORM INJURY

A practical method of avoiding wireworm injury to crops is not to plant susceptible crops where wireworms are abundant. This applies especially to potatoes, for the best potato soil is likely to be free from wireworms. Caribou loam, a yellowish brown silt loam containing considerable shale fragments and gravel, is quite common in Aroostook County, and is seldom heavily infested by wireworms. There are also on Maine farms of other sections, areas of light loam soil, on which wireworms are rarely found in excessive numbers and which are especially well adapted to potato culture. The use of green manure crops in the rotation permits the maximum use of soil particularly adapted to potato growing.

While potatoes have been emphasized in relation to utilization of the best land in order to avoid wireworm injury the same rule holds for other crops which are susceptible to injury by wireworms. Hay crops and grain crops can be grown in areas where wireworms are relatively abundant, while corn, potatoes, and vegetables can be grown more profitably on lighter soil where wireworms are not so abundant. Land utilization is discussed because it can be applied in preventing crops from being needlessly injured by wireworms under certain local conditions. However, when it is necessary to use wireworm infested soil for producing crops, infestations can be controlled by cultivation and crops susceptible to injury can then be safely grown.

#### THE EFFECT OF CROP ROTATIONS UPON THE ABUNDANCE OF WIREWORMS

The kind of crop which may be grown in a given area determines to a large extent the limits of crop rotations. A large number of the field and vegetable crops of Maine are subject to wireworm injury. Flowering plants of several kinds are also injured by these pests and even weeds are subject to attack by wireworms (see food plant list, p. 6). King (1928, p. 700) reports that where wild mustard, *Sinapis (Brassica) arvensis* L., becomes abundant in fields infested by wireworms, these insects disappear almost at once. White mustard, *Brassica alba* L., is claimed by Curtis (1840, p. 186), Fitch (1867, p. 537), and others to be immune to the attack of wireworms.

The clovers are a most useful group of plants for crop rotations in soil infested by wireworms. In Maine, red clover is practically immune to the attack of the wheat wireworm and *Melanotus* sp. of any plant commonly grown in the fields. On the other hand, wild mustard, field kale or charlock, *Brassica arvensis* L., was found to be a favored food plant of larvae of *Limonius* sp. Wireworms of this group fed upon wild mustard in preference to corn, and to quack grass, *Agropyron repens*, and other weeds.

Some crops are much more subject to injury by wireworms than are others. Such crops should be placed in the rotation to come at a time when the wireworms are reduced in number. It is

difficult to list plants in order of their susceptibility to wireworm injury because of the many factors which enter into the relationship between wireworms and the amount of feeding done. For instance, potatoes are not always the preferred food and yet the potato crop undoubtedly is more seriously injured by wireworms than any other crop in Maine, for not only are the seed and growing plants affected but the mature tubers are injured. However, the amount of injury done to this crop depends upon other factors, as well as the number of wireworms present in the soil.

The wheat wireworm is more readily attracted to sprouting wheat than to sprouting potato seed pieces and yet only the heaviest infestations of wireworms ordinarily injure wheat so that the injury is significant. The seeming resistance of wheat is not due to any degree of immunity of the plants but rather to the relatively great number of plants which grow within a given area as contrasted with row or hill crops. Likewise other broadcast crops such as oats, grass and legumes often survive where corn or potatoes would be seriously injured. Although the number of plants growing within a given area is important in the survival of a crop when wireworms are present, certain plants are preferred as food. This is shown by the number of larvae which are attracted to different kinds of plants in wireworm infested areas. In general, leguminous plants are not preferred food plants of wireworms, although clover and beans are sometimes eaten by wireworms when other food is scarce or absent from their environment.

Potatoes may be seriously damaged by 4 or 5 wireworms per square yard if the infestation at this rate is distributed over a large area. Potatoes may be produced profitably in a field where only a small area is infested by wireworms. An average of 10 to 20 wireworms per square yard sometimes does not affect the growing of corn. However, from 30 to 60 wireworms per square yard are sometimes disastrous to the corn crop. Ten wireworms or less per square yard or about 48,000 or less per acre have not been found to injure growing corn seriously in Maine, providing good methods of cultivation and fertilization are employed. Oats and broadcast grain or grass crops are able to withstand even greater wireworm populations. Just what populations of wireworms these crops are able to withstand is somewhat problematical, although limited data show that around 87 wireworms per square yard or about 425,000

per acre are known to entirely destroy the oats crop within an area so infested. Roebuck as already cited (p. 84) has worked out the tolerance of certain crops to wireworm populations.

No observed or recorded instance of a wireworm population being of sufficient severity to destroy a crop of common red clover is known. Peas planted in drills, in rows 6 to 8 inches apart, as raised for commercial canneries, are often grown in areas of wireworm populations of from 100,000 to 400,000 per acre without any apparent effect upon the crop. Field beans grown for dried beans are often planted in soil containing many wireworms. Since beans are grown in rows about a yard apart and there is a smaller number of plants per unit area, the crop is more likely to be injured than are peas which are planted much closer together. It would appear that peas as grown for the canneries would be an excellent crop to be grown in wireworm infested territory for the purpose of reducing the wireworm population. Such is not always the case, however, for not only are the peas uncultivated at the time of mating and egg laying by the adult wireworms but often grass is seeded with the peas. Peas grown in rows and cultivated are much more desirable from the standpoint of reducing the wireworm population. Grass crops such as timothy and redtop grown in wireworm infested fields provide conditions ideal for building up large wireworm populations. It is seldom that the populations become abundant enough to entirely destroy such hay crops but it is known that these grasses are fed upon by wireworms. It is also known that on rare occasions wireworms are responsible for the destruction of timothy. Extreme injury of this type is sometimes called "running out" of the crop.

The use of crop rotations in wireworm control is a practice long advised by entomologists. Forbes (1892, p. 44) advocated the planting of clover after plowing up grassland and before planting corn. Webster (1892), Conradi and Eagerton (1914, p. 15) and others also recommended crop rotations of various kinds. Rawlins (1934, p. 311) says: "Field studies show a very definite relation between rotations and abundance of wireworms."

In Maine the relation between wireworm abundance and crop rotation has been shown by contrasting the wireworm population of soil where cultivated crops were grown continuously with that of

soil which had been freed of wireworms and then seeded to timothy. In the former case, after three years of cultivation, an average of approximately 2 wireworms per square yard were present and where grass was grown for 3 years an average of 33 wireworms per square yard was found. In these plots the original infestation varied somewhat but ranged from approximately 10 to 80 wireworms per square yard.

Since cultivation is an effective although somewhat slow method of controlling wireworms, cultivated crops should be used as often as possible in the rotation and uncultivated crops should be omitted as often as practical.

A good deal of attention has been given to crop rotation for the control of wireworms in connection with potato growing. At first a rotation using oats and red clover in the rotation with potatoes was advocated and while this was better than the older practice of seeding the land to timothy and clover, the growing of oats and clover in wireworm infested soil had serious objectionable features. It was found that some wireworms were evidently being hatched from eggs laid in the field during the time oats and clover were growing. Investigations disclosed that during the first year when clover was seeded together with oats the adult beetles found conditions suitable for egg laying in the fields and often conditions favorable to wireworms existed the second year due to grass or weeds growing in the clover field. The grower also lost the use of his soil for cultivated crops for two years and a relatively small amount of humus was added to the soil by this method as compared to plowing under a green manure crop.

Green manure crops are advocated in crop rotations in wireworm infested soil. Besides for their usefulness in wireworm control they are advised for building up the humus content of the soil and thus increasing yields of crops. An annual plant which grows late in the season and can be planted as late as July 1 or even later is desirable. Late planting of green manure crops permits cultivation during at least a part of the season when the eggs are laid from which our common wireworms hatch. Cultivation during the month of June is especially desirable to keep down weeds and discourage mating and egg laying by female beetles. Crimson clover and buckwheat are crops that are used for green manure and still may be planted late. In addition to being good green

manure crops neither is apparently especially well liked by the common wireworms of Maine. These crops have been used successfully in crop rotations, experimentally for wireworm control, and by Maine farmers as well. While it is better to plant these crops July 1 or after, especially if the wireworm population is large, both crimson clover and buckwheat can be planted earlier. This may be desirable in some cases and may be done with relatively little danger of greatly increasing the wireworm population if the wireworms and beetles have been largely eradicated by previous years of cultivation.

#### THE EFFECT OF NAPHTHALENE UPON WIREWORMS

Naphthalene has long been used in the control of clothes moths. It was used by Glasgow (1931) for controlling the carrot rust fly. He is of the opinion (p. 195) that naphthalene should prove an exceedingly useful insecticide in combating not only the carrot rust fly but possibly other similar soil inhabiting pests as well. In his experiments, Glasgow found that crude naphthalene persisted for a longer time in the soil than the refined grades of naphthalene. Naphthalene was used by Headlee (1929, p. 193, 194) in experiments to test its effect upon wireworms. He used it mixed with the soil in tin pans in which the wireworms were placed. Headlee found that at temperatures of 70° F., or above, soil which is mixed with flake naphthalene at the rate of 3,000 to 1 is deadly to wireworms. The blanket method, that is the mixing of the soil and naphthalene on top of a lower layer of untreated soil, was then tried. In general this method was found unsatisfactory. Theobald (1923) recommended naphthalene for the control of wireworms in England. Naphthalene was advised as a substance useful for the control of wireworms in Czechoslovakia by Rambousek (1926). A combination of 1 ounce of naphthalene dissolved in 3 ounces of carbon disulphide rendered miscible by the addition of one fluid ounce of oil soap spirit was recommended against wireworms in Germany by Krauss (1931).

Preliminary laboratory tests of naphthalene for its effect on wireworms was made in Maine in 1929. Field tests were made in 1931. These experiments were on the whole unsatisfactory. It was not until April of 1932 that pot experiments with naphthalene

in the greenhouse indicated that this substance is toxic to wireworms. When mixed with the soil in 5-inch pots at the rates of one-half to one ounce per pot naphthalene killed all the wireworms in a few days' time, while only one wireworm died in the soil of the untreated pots during the same period.

Field tests were again made in 1932. Plots were laid out 30 by 90 feet, samples of the wireworm population were taken on June 3, and crude naphthalene was applied at the rates of approximately 272 pounds, 554 pounds, and 360 pounds per acre to plots one, two, and five respectively. Two plots were maintained without treatment of naphthalene as checks against the treated plots (Table 28). All plots were planted to corn and they were all given

TABLE 28

*Crude Naphthalene in Relation to Wireworm Control  
During 1932*

Plot	Pounds per acre of naphthalene added to soil	Wireworms per sq. yd.		Per cent wireworm reduction June to September
		On June 3	On September 8	
1	272	24	4.0	83.3
2	554	20.5	2.5	87.8
3	0	22.5	5.0	77.8
4	0	10.0	3.5	65.0
5	360	22.0	5.5	75.0

the same subsequent treatment. There was a reduction of wireworms in all the plots. However, the reduction was somewhat less in the untreated plots than in those treated with naphthalene, there being a difference of approximately 11 in the average percentage in favor of the treated plots. The naphthalene appeared to have affected the presence of other insects, for carabid beetles and therewith larvae were plentiful in the untreated plots but were very scarce in the plots treated with naphthalene. In September, the soil of the treated plots was permeated by a faint odor of naphthalene and occasionally the flakes could still be found in the soil.

Further tests of naphthalene were made in field experiments for wireworm control during 1933. Four plots were treated as shown in Table 29.

TABLE 29

*Naphthalene in Relation to Wireworm Control During 1933*

Plot	Pounds per acre of naphthalene added to soil	Wireworms per sq. yd.		Per cent wireworm reduction April to October
		On April 27	On September 8	
20	300	8.0	2.2	72.5
21	No treatment	6.0	1.0	83.3
22	400	19.0	1.2	93.7
23	No treatment	7.0	3.0	57.1
24	500	65.0	0.6	99.1
25	No treatment	19.0	1.5	92.1
26	600	16.0	0.2	98.7
27	No treatment	9.0	0.2	97.8

There was a difference of approximately 11 in the average percentage of reduction in the wireworm population from June to September in favor of those plots treated with naphthalene over those receiving no naphthalene. However, since the numbers of wireworms in the untreated plots were smaller to start with than in those treated, the results are not directly comparable. The cost of the naphthalene was approximately \$3.50 per hundred pounds and this extra cost and the labor involved would hardly be justifiable on the basis of the greater reduction in the wireworms of the treated plots as compared to those untreated. Neither would the extra cost be justified by extra protection afforded to the potato tubers from wireworm injury, for there was a difference of but approximately three in the percentage of injured tubers in the plots, this being less in those receiving naphthalene.

Naphthalene applied in the plots at the rate of 300 and 400 pounds per acre apparently did not affect the color of the foliage or vigor of the plants. However, in the plots treated with naphthalene at the rate of 500 and 600 pounds per acre respectively, although the plants were late in starting, the color of the foliage was a little lighter green and the plants were healthier looking and more vigorous after they became well established, than those in the checks. There was little difference in the yield of potatoes between the plots treated with naphthalene and those not treated. Such differences as existed could easily have been caused by variations in the soil of the plots.

It was thought by Glasgow (1931, p. 196) that the stimulating effect noted in case of certain crops may be due, in part, to the naphthalene checking the activities of certain obscure animal or plant organisms in the soil that may exert to some degree an inhibiting action on plant growth. Glasgow quotes W. O. Gloyer who says in part: "It is hoped that in the case of special crops the presence of naphthalene for a short period of time may be found to afford sufficient fungicidal protection to enable the plant to escape infection during a critical period when it is most susceptible to a given parasite." It is not within the province of this paper to remark upon the possibilities of protection of potatoes from diseases, other than that if naphthalene should prove to be a fungicide as well as an insecticide, its use would be more practical. That naphthalene does have some effect upon the foliage of potatoes late in the season is indicated by these experiments. The exact nature of the effect is left to those specialists working in the field of plant physiology.

Naphthalene has not proven practical in our field tests for the control of wireworms. There is an indication that it does have some effect on wireworms and it is hoped that further experiments may clear up certain facts concerning its use.

#### THE EFFECT OF KAINIT UPON WIREWORMS

Kainit was recommended more than forty years ago as a substance giving promise of being useful in wireworm control (Smith, 1891). Comstock and Slingerland (1891, p. 235) experimented with kainit and were of the opinion that it had little effect on wireworms. Riley and Howard (1892), Lintner (1896), Webster (1899), and Herrick (1925, p. 299) are of the opinion that kainit has little value in wireworm control. On the other hand Fernald (1899), Chittenden (1912), and Orton and Chittenden (1917) recommend its use. Whether or not kainit has any value as an insecticide or repellent for wireworms is a somewhat debatable question if the American literature on the subject alone is considered.

The use of kainit for wireworm control is more generally recommended in Europe than it is in America. Weigand (1924, p.

1017) recommends 530 pounds of finely ground kainit per acre in constantly infested fields and notes that it should be dug in during wet weather while hoeing the plants. Malenotti (1927, p. 123) is of the opinion that the use of kainit does more than repel the larvae, as it drives them down to depths where there are unfavorable conditions such as low temperature and increased moisture, exposing them to various infections. Langenbuch (1933) working with the larvae of *Agriotes lineatus* L. and *Agriotes obscurus* L. found that they migrated from soil in which a solution of water and kainit had been mixed at the rate corresponding to those used in the field. The action of the kainit was found to be due chiefly to a disturbance of the water economy of the wireworms. The highly hygroscopic salt increases the absorbent power of the soil which thus withdraws water from the body fluid of the larvae until thirst compels them to ingest the salt solution in the soil, and the salt ions then injure their muscular and nervous systems.

Larvae of *Agriotes mancus* Say and of *Melanotus* sp. were used by the writer in an experiment in Maine to test the effect of kainit. A box was set up and into one end was placed soil alone. In the other end of the box a mixture of soil and kainit was used, the amount of kainit being approximately at the rate of 1,000 pounds per acre. Into the middle of the soil of each section an auto-irrigator was inserted in order to supply a like amount of moisture to each end of the box. Sprouting wheat was mixed with the soil to provide food for the wireworms. On March 28, 1929, thirty wireworms were placed in the soil mixed with kainit. On April 12 there was little movement except that the wireworms had grouped themselves close about the auto-irrigator in the end of the box where the soil contained kainit. An examination of the soil made on April 26 disclosed that twenty of the larvae had moved away from the soil containing kainit to the end of the box where the soil was free from kainit. These results indicate that there was at first a movement toward the auto-irrigators to escape the more concentrated solution of water and kainit and that the final movement was away from the soil containing kainit. It is thought that the water furnished to the soil by the auto-irrigators was sufficient in quantity to make the salt solution in the soil bearable to the wireworms for a while, and that finally the amount of solution for that part of the box containing kainit in the soil was lowered

and the wireworms, irritated somewhat by the remaining trace of the kainit, moved away from the source of irritation.

A six inch flower pot was filled with sterilized soil in which 3 ounces of kainit had been mixed. The hole in the bottom of the pot was stopped with plaster of Paris and sprouting wheat was placed in the soil as food for the twelve wireworms used in this experiment. Another pot set up as the first, except that no kainit was added to the soil, was used as a check on the first pot. The pots were watered sufficiently to keep them moist but not wet. Wireworms were placed in the pots on April 26, 1929. On May 15, 1929, four of the twelve larvae in the pot containing kainit were dead. On June 10 all those in this pot were dead while but one had perished in the check pot. This indicated that kainit was toxic to wireworms when used in large amounts.

In 1932 field trials of kainit were made to test the effect upon wireworms. Plots used were 30 by 45 feet in size and an average of 33 wireworms per square yard were present in these plots. Four plots were used, two being treated with kainit at approximately 450 pounds per acre and the other two being maintained untreated as checks. Twenty-two wireworms per square yard were present in the check plots at the start of the experiment on June 6, 1932. Sweet corn was planted in all four plots and they were given like treatment in the matter of cultivation. On September 8, 1932, soil samples were taken from each of the four plots. In untreated plots the average wireworms per square yard remaining on September 8 numbered 23½ while in the treated plots the average number was but 4 per square yard. In one of the two plots treated with kainit, no wireworms could be sifted from the soil even when repeated attempts were made to find them. In this case the kainit was sown broadcast by hand and harrowed thoroughly in a rotary path around the plots so as not to drag the kainit from one plot to another. During cultivation the cultivator gangs were lifted at the end of the plots for the same reason. The reduction of the wireworm population in the treated plots indicated that kainit affected the wireworms either by causing death or by driving them out.

Preliminary investigations with kainit during 1932 indicated that its use was practical for the control of wireworms. Consequently, in 1933 plots were again laid out and kainit was used in amounts varying from 300 to 1,000 pounds per acre. Kainit was

applied to nine of eighteen plots on April 27 and 28 and the remaining nine plots were maintained as checks. Twenty-one hundred pounds of 4-8-7 fertilizer was applied to all the plots and potatoes were planted on May 8. The potatoes were hilled and cultivated according to the methods usually employed in potato growing in Maine.

The plots were arranged in the well-known checkerboard fashion and were all 30 by 45 feet. Samples taken from each plot consisted of 135 square feet of surface area, the soil being removed to such depth that wireworms were no longer found. Both the check plots and those treated with kainit were planted to potatoes. Except for the addition of kainit to the treated plots, all received the same treatment in regard to cultivation, fertilization, and spraying.

A general survey of the field after the potato plants had reached a height of six inches or more revealed at once that there were differences, in the plants, which set the treated plots off from the checks and in some cases from each other. An examination of the plants made on July 19 showed the foliage of potato plants in plot 6, which was treated with kainit at the rate of 600 pounds per acre, to be somewhat lighter green in color and the plants were more vigorous than in the check plots. The potato plants in plot 10 were late in starting, there being many small plants and some missing hills at the date of examination. Kainit was applied at the rate of 800 pounds per acre in plot 10. The general condition of potato plants in plot 10 also prevailed in plot 12, where kainit was applied at the rate of 900 pounds per acre. The potato plants growing in plot 14 were smaller and less vigorous than those growing in any of the plots regardless of treatment. Kainit was applied to the soil of plot 14 at the rate of 1,000 pounds per acre. The soil in plot 18 was treated with kainit at the rate of 800 pounds per acre and quicklime at the rate of 400 pounds per acre. Potato foliage in this plot was lighter in color than in the check plots. Plot 8 which received kainit at the rate of 700 pounds per acre did not show any effect from the treatment in color or vigor of the foliage when compared to the check plots. Plots 16, 2, and 4 treated with kainit at the rate of 300, 400, and 500 pounds respectively were not noticeably different with respect to vigor and appearance of the plants. Data obtained from these plots and their checks are shown in Tables 30 and 31.

TABLE 30

*Plots Planted to Potatoes in 1933 and Maintained as Checks  
Against Those Treated with Kainit*

Plot number	Wireworms per acre		Per cent reduction in wireworm population	Percentage of tubers injured
	April	October		
1	34,080	13,200	61.27	42.0
3	34,080	5,280	84.51	7.2
5	62,920	5,280	91.61	44.2
7	174,240	8,630	97.92	35.4
9	116,160	990	99.15	10.7
11	121,000	2,310	98.09	58.9
13	72,600	2,640	96.36	50.8
15	16,940	1,950	70.78	18.9
17	145,200	7,590	94.77	6.9
	777,220	— 45,870 = 731,350		
Average per cent reduction in wireworm population for untreated plots April to October — 88.27				

Counts of wireworms were taken in each plot in April and again in October. The greatest reduction in the wireworm population occurred during this period in plot 4 which received kainit at the rate of 500 pounds per acre (Table 31). In April there were present in the soil of this plot wireworms at the rate of 639,000 per acre, most of which were larvae of *Cryptohypnus abbreviatus* Say.

TABLE 31

*Plots Treated with Kainit in 1933 and Planted to Potatoes*

Plot number	Amount kainit per acre	Wireworms per acre		Per cent reduction in wireworm population	Percentage of tubers injured
		April	October		
2	400	77,440	8,910	88.50	25.1
4	500	639,200	2,640	99.59	33.9
6	600	116,160	88,280	67.06	79.0
8	700	116,160	44,550	61.65	64.7
10	800	140,360	4,620	96.71	59.3
12	900	87,120	2,310	97.85	42.1
14	1000	58,080	2,640	95.45	3.6
16	300	57,480	5,610	90.25	35.2
	1,292,000	— 109,560 = 1,182,440			

Average per cent reduction in wireworm population for treated plots April to October — 87.07

Wireworms remaining in the fall at the rate of 2,640 per acre were of *Agriotes mancus* Say and *Melanotus* sp. Since the larvae of *Cryptohypnus abbreviatus* have a shorter life cycle than *Agriotes mancus* and *Melanotus* sp. it is probable that the larvae of *Cryptohypnus abbreviatus* had emerged as adults before the fall counts were made. Reduction of wireworms was not consistent with increases in the amount of kainit applied in any of the plots treated.

There is the possibility that the relatively heavy application of kainit in plot 14 was responsible for the reduction of tubers injured in that plot by wireworms. The per cent of tubers injured was less in plot 14 than in any other plot, treated or untreated. Negative evidence only was obtained if all of the plots are considered, for there was an average reduction of 88.27 per cent in the wireworm population in the untreated and an average of 87.07 per cent reduction in the wireworm population of the plots treated with kainit. Therevid larvae and both adults and larvae of Carabidae were numerous in the plots and may have accounted for some of the inconsistencies not otherwise explainable.

During 1934, plans were again made for experiments with kainit in wireworm control. The site selected was on a farm where wireworms are always abundant when cultural practices are favorable for their accumulation. Plots were established in a field which had been seeded to grass and had been cut for hay for three years. Counts of the wireworm population were taken in the spring and the sod was then plowed and planted to potatoes. The entire area included in the plots was treated in the same way in regard to all cultural practices, fertilization, and spraying. One-half the plots included kainit at the rate of 1,000 pounds per acre. Each plot was 330 feet in length and 9 feet in width. The plots were alternately treated with kainit, every other plot remaining without kainit. The data obtained are shown in tabular form (Table 32).

The wireworm population was taken by sifting the insects from the soil underlying 156 square feet of surface of each plot. The soil was removed to such depth as was necessary to obtain all the wireworms, usually 6 to 9 inches. The samples were taken at regular intervals in each plot.

During the growing season there was little difference between the potato plants in plots having the kainit and those in the check plots except that the plants in plot 1 did not come up evenly, were

not as thrifty at any time as in the other plots, and did not yield quite as well as the others.

TABLE 32

*Experimental Plots for Testing the Possible Effect of Kainit on Wireworms in 1934*

Plot number	Treatment	Wireworms per acre		Percentage of tubers injured	Average punctures per tuber	Average percentage of reduction in wireworms
		Spring	Fall			
1	Kainit	74,060	73,800	41.1	1.24	54.33
2	Check	97,700	40,100	66.4	1.66	57.93
3	Kainit	94,800	41,600	71.4	1.88	56.12
4	Check	65,800	48,400	66.4	3.39	26.44
5	Kainit	151,400	70,600	68.0	6.37	53.37
6	Check	150,000	90,200	59.4	9.85	39.87
Averages for treated plots		106,733	50,333		3.16	54.61
Averages for untreated plots		104,500	59,566		4.97	41.44
Difference in yield 160 pounds in favor of treated plots						

There was but slight difference in the percentage of potatoes injured in the plots treated with kainit as compared with those which received no kainit (Table 32). The number of punctures per tuber was slightly greater in the check plots than it was in those treated with kainit. Although there was a reduction of 54.61 per cent in the plots treated in contrast with 41.41 per cent in those untreated, this difference is not significant as the odds are almost 3 to 1 that such reduction might have occurred from other causes than the treatment.

In summing up the results of three years of field trials in the use of kainit for wireworm control, it is apparent that kainit cannot be used with any degree of certainty in controlling wireworms. The chemical composition of kainit is variable and this may account for a relative degree of success one year as compared to another. There was an increase of approximately 160 pounds in yield of potatoes for plots treated with kainit in 1934 over those untreated. The added expense and labor involved in the use of kainit for wireworm control could hardly be justified by the data obtained in our experiments.

Laboratory trials with kainit have indicated that it is toxic to wireworms when used in excessive amounts. This opens up the question of what the toxic element of kainit is. Magnesium chloride and magnesium sulfate are found in kainit. Common salt ( $\text{NaCl}$ ), hydrated magnesium lime, and basic slag are also found in kainit. It is known that salt in large quantities is toxic to wireworms and basic slag has been reported as an effective measure against wireworms (Unov, 1913).

THE EFFECT OF CERTAIN MAGNESIUM SALTS UPON THE WHEAT  
WIREWORM, *Agriotes mancus* Say

Magnesium chloride and magnesium sulfate were tested in the laboratory for their effect on wireworms. Common 6-inch flower pots, with the drain holes stopped to prevent the escape of the wireworms, were used to hold the soil including the magnesium salts. Pieces of potatoes were added as food for the wireworms and ten larvae of *Agriotes mancus* Say were then placed in each pot. The soil of the pots was kept moist by watering at regular intervals. The results are presented in Table 33.

TABLE 33

Toxicity of  $\text{MgSO}_4$  and  $\text{MgCl}_2$  to Larvae of *Agriotes mancus* Say

Salt	Concentration	Time after which larvae were dead or missing <sup>1</sup>					
		1 day	2 days	3 days	4 days	5 days	6 days
$\text{MgSO}_4$	1:34.6	3	8	10			
$\text{MgSO}_4$	1:23	10					
$\text{MgSO}_4$	1:17	7	8	Two missing			
$\text{MgCl}_2$	1:13.5	5	7	7	8	9	10
$\text{MgCl}_2$	1:19.5	10					
Check	0	0	0	0	0	0	0
Check	0	0	0	0	0	0	0

<sup>1</sup> Numbers under this heading indicate dead larvae unless otherwise noted

These tests although preliminary indicate strongly that magnesium sulfate and magnesium chloride are toxic to larvae of *Agriotes mancus* when used at concentrations of from 1:35 to 1:14.

## THE EFFECT OF OTHER SUBSTANCES UPON WIREWORMS

Paradichlorobenzene was recommended as a soil fumigant for wireworms in California by Essig (1926). Field trials of this substance for the control of wireworms were made in the spring and summer of 1928. In all cases the results were negative.

Calcium chloride used at the rate of 1,000 pounds per acre did not kill the wireworms and the reduction of the wireworm population from spring to fall in this plot was about the same as in a plot maintained as a check.

Sodium chloride was used at the rate of 700 pounds and 800 pounds per acre, the effect being negative in that there was no significant effect on the wireworm population as compared with check plots which were maintained. Wireworms were found living in soil reclaimed from a salt marsh. When analyzed this soil was found to contain as much as 1.25 per cent of common salt ( $\text{NaCl}$ ).

Hydrated lime was used in a laboratory test of its effect on wireworms. When it was used in excessive amounts in these tests, wireworms migrated to soil free from lime. Lump lime (oxide of lime) was then used in the field at the rate of 1,000 pounds per acre. Check plots were maintained and no significant reduction of wireworms occurred in the plots limed as compared with those unlimed.

Mercurous chloride (calomel) was used in a laboratory test of its effect on the larvae of *Agriotes mancus* Say. Two 9-inch pots, in which the drain holes were stopped to prevent the escape of the wireworms, were used. Twenty wireworms were placed in each of two pots. In one, one-fifth of an ounce of mercurous chloride was added as a suspension in water. The other pot was maintained as a check without treatment. The results were as follows: In the pots treated with mercurous chloride two larvae were dead in five days' time, fourteen were recovered, and four could not be found. At the end of nine days two more had died and in fifteen days all but six were dead. All the larvae continued to live in the pot used as a check.

Seed corn was treated by soaking it in a solution of mercurous chloride one ounce to 8 gallons of water. This corn was then planted in soil and 10 larvae of *Agriotes mancus* placed in each of two containers used. Two other containers each with the same amount of soil and untreated corn were provided with 10 wireworms apiece

and were used as checks. Both the treated and untreated corn was eaten without any apparent ill effects. Potato seed pieces treated with mercurous chloride as described above were eaten into without any apparent ill effects to the wireworms.

In general, these preliminary experiments indicate that mercurous chloride is somewhat toxic to wireworms when used in the soil but a high concentration would be required to obtain a reasonable control. Used as seed treatment, mercurous chloride appears to have little repellent or insecticidal effect on wireworms when used at the rate of one ounce to 10 gallons of water.

Sulfur was used at the rate of 2 ounces in a 6-inch flower pot filled with soil and 12 larvae of *Agriotes mancus* were introduced into the pot. Six wireworms were dead at the end of 15 days and all were dead in 30 days' time. None of the 12 larvae kept in a pot of soil without sulfur were dead at the end of 30 days.

One-fourth ounce of carbon tetrachloride was mixed into the soil of a 9-inch flower pot containing 23 larvae of *Agriotes mancus*. At the end of 10 days but 3 wireworms were dead. Seventeen wireworms were returned to the pot and the dose was doubled. This dosage killed 7 of the wireworms added. The remaining 10 were returned to the pot and 6 were still alive at the end of a month's time. Twenty-three larvae were kept in the untreated soil of a pot as a check, 2 of which had disappeared during the time this test was in operation but none of which were found dead.

Ground tobacco stems were used in a preliminary way during 1934 to test its possible effect on wireworms. Tobacco was applied to the soil at the rate of 1,000 pounds per acre. The potato plants grew vigorously and were noticeably larger throughout the season than those in the check plots. However, as far as the effect on decreasing the wireworm population was concerned, tobacco was apparently without value.

Cyanamid was also used in the 1934 tests of substances for their value in wireworm control. Cyanamid at the rate of 1,000 pounds per acre apparently affected the stand of potatoes planted in the plot, as many hills either were missing or contained plants which lacked vigor. However, little difference in yield, in this plot as compared with check plots, was evident at the time of digging. The reduction of wireworm population in the soil treated with cyan-

TABLE 34

*Baits for Elaterid Larvae, August, 1926*

Bait number	Bait	Number larvae attracted
1	Graham flour dough	5
2	" "	11
3	" "	7
4	" "	9
5	" "	4
6	" "	3
7	" "	3
8	" "	7
9	" "	6
10	" "	9
11	" "	1
Average larvae attracted per bait		Total 65
1	Wheat	21
2	"	16
3	"	27
4	"	15
5	"	60
6	"	19
7	"	19
8	"	36
9	"	37
10	"	10
11	"	7
12	"	10
13	"	11
14	"	1
15	"	4
16	"	6
17	"	10
18	"	6
19	"	3
20	"	3
21	"	15
Average larvae attracted per bait		Total 336
1	Corn	6
2	"	13
3	"	8
4	"	7
5	"	12
6	"	0
7	"	1
8	"	1
9	"	17
10	"	19
11	"	18
12	"	15
13	"	3
14	"	23
15	"	7
Average larvae attracted per bait		Total 150
1	Oats	3
2	"	3
3	"	1
4	"	0
5	"	2
6	"	0
7	"	1
8	"	4

Bait number	Bait	Number larvae attracted
9	Oats	2
10	"	3
11	"	4
12	"	0
Average larvae attracted per bait		1.9
Total		23
1	Potatoes	0
2	"	0
3	"	1
4	"	2
5	"	1
6	"	0
7	"	0
8	"	2
9	"	2
10	"	2
11	"	0
12	"	0
13	"	0
14	"	1
Average larvae attracted per bait		.79
Total		11

amid at the rate of 1000 pounds per acre was not significantly greater than that in check plots.

#### THE USE OF BAITS FOR WIREWORMS

Sweetened meal poisoned with Paris green was used by Bethune (1905) for baiting wireworms. Potatoes have often been used in Europe as baits for attracting elaterid larvae. Weldon (1915) reports the use of potatoes as baits to protect beans from the attack of wireworms in California. Roasted and unroasted rice shorts are recommended by Treherne (1919) and Ruhmann (1928). Spuler (1925) used various substances to test their attractiveness to wireworms and Campbell (1926) reported the use of peas, beans, and corn.

The writer began work on the problem of attracting wireworms to baits in August, 1926. Graham flour dough, wheat, corn, oats, and potatoes were used. The number of larvae attracted is shown in Table 34.

The data in Table 34 indicate that wheat was the most attractive of the baits used for wireworms during 1926.

TABLE 35

*Baits for Elaterid Larvae, August, 1928*

Bait number	Bait	Number larvae attracted
1	Graham flour	4
2	" "	10
3	" "	7
4	" "	3
5	" "	4
6	" "	3
7	" "	7
8	" "	3
Average number of larvae per bait		Total 41
1	Graham flour with honey added	4
2	"	1
3	"	1
4	"	11
5	"	16
6	"	0
7	"	5
8	"	30
9	"	11
10	"	6
11	"	7
12	"	1
Average number of larvae per bait		Total 93
1	Wheat	5
2	"	5
3	"	7
4	"	7
5	"	5
6	"	1
7	"	5
8	"	14
9	"	3
10	"	10
11	"	41
12	"	21
13	"	2
14	"	3
15	"	8
16	"	7
17	"	4
18	"	5
Average number of larvae per bait		Total 153
1	Oats	11
2	"	7
3	"	15
4	"	7
5	"	3
6	"	8
7	"	8
8	"	2
9	"	11
10	"	4
11	"	6
12	"	2
13	"	13
Average number of larvae per bait		Total 97

Bait number	Bait	Number larvae attracted	
1	Corn	11	
2	"	7	
3	"	0	
4	"	0	
5	"	11	
Average number of larvae per bait		Total	29
1	Potatoes	1	
2	"	5	
3	"	3	
4	"	2	
5	"	6	
Average number of larvae per bait		Total	17

Baits of the kinds used during 1926 were tried during the spring of 1927, but so few wireworms were attracted that the results were not tabulated. Baits have been repeatedly used during the spring seasons and only in one instance have they proven effective in attracting wireworms. This instance is noted in connection with soil fumigations (p. 129). In general, baits are not effective in Maine for attracting wireworms during spring.

During the summer of 1928 another experiment in baiting wireworms was outlined and put into effect. The data obtained are given in Table 35.

Clover was cut and placed in the soil, twenty baits attracted 8 larvae. Of Yellow Eye Beans, 20 baits attracted 3 larvae. Of

TABLE 36

*Baits for Elaterid Larvae, August, 1932*

Bait number	Bait	Average number of larvae attracted
1	Beans	0.80
2	Wheat	4.60
3	Potatoes	3.80
4	Buckwheat	8.20
5	Corn	3.00
6	Oats	4.00
7	Corn meal	4.20
8	Bran	1.00
9	Graham flour	4.20
Total Average		33.80 8.76

garden peas, 20 baits attracted 6 larvae. Wheat was again the most attractive bait used.

Baits of flour, meal, bran, and seeds were used in 1932 (Table 36) and their effectiveness in attracting wireworms was compared to baits of graham flour dough to which substances were added to increase its attractiveness (Table 37).

TABLE 37

*Baits for Elaterid Larvae with Other Substances  
Added, August, 1932*

Bait number	Bait	Average number of larvae attracted
1	Graham flour and bone meal	2.00
2	Graham flour and fish meal	4.00
3	Graham flour and honey	3.40
4	Graham flour, banana, and yeast	5.20
5	Graham flour and molasses	12.00
6	Graham flour and lemon juice	7.50
7	Graham flour and orange juice	9.00
8	Graham flour and animal tankage	4.20
	Total	47.30
	Average	5.91

Ten baits of each kind were used and they were placed about three inches deep in the soil (Table 37). The wireworm infestation varied somewhat in intensity in the different parts of the field but as the baits of the various kinds were placed in rotation in the row, the test appears to be a fair one. It is especially noticeable that graham flour attracted an average of 4.20 larvae per bait (Table 36). When molasses was added the average number attracted was 12 (Table 37). Orange juice added to the graham flour baits attracted more larvae than the plain baits. Lemon juice and banana and yeast also apparently increased the attractiveness of graham flour baits to wireworms.

Aromatic substances were added to graham flour dough with the thought that they might increase the attractiveness of the baits for wireworms (Table 38).

None of the aromatic substances named in Table 38 were as attractive when added to graham flour baits as were molasses,

TABLE 38

*Baits for Elaterid Larvae with Aromatic Substances  
Added, August, 1932*

Bait number	Bait	Average number of larvae attracted
1	Graham flour and clove oil	5.20
2	Graham flour and geraniol	2.80
3	Graham flour and isoamyl valerate	3.60
4	Graham flour and isoamyl propionate	2.80
5	Graham flour and terpineol acetate	3.40
6	Graham flour and linalool	3.60
7	Graham flour and linalyl acetate	3.00
8	Graham flour and artificial musk	3.80
	Total	28.20
	Average	3.53

orange juice, or lemon juice. Clove oil was about equal to banana and yeast in attractiveness.

Poisonous substances were added to baits of graham flour to test their insecticidal value for wireworms. They were used as solutions or suspensions in water, the water then being used to moisten the dough. Poisons were used at the rate of 1 part to 50 parts of dry graham flour by weight and 1 part to 100 parts of the flour by weight. Ten baits of each poison were used. The results are presented in Table 39.

The baits containing sodium arsenate were eaten into by wireworms. Wireworms removed from these poisonous baits survived

TABLE 39

*Baits for Elaterid Larvae with Poisonous Substances  
Added, August, 1932*

Bait number	Bait	Number of larvae killed
1	Graham flour and sodium arsenate	0
2	Graham flour and strychnine	0
3	Graham flour and amyl alcohol	0
4	Graham flour and mercurous chloride	0
5	Graham flour and mercuric chloride	0
6	Graham flour and arsenious oxide	0
7	Graham flour and Paris green	0
8	Graham flour and lead arsenate	0
9	Graham flour and calcium arsenate	0

for 30 days after removal. All poisons used except sodium arsenate acted as repellents.

#### THE USE OF CALCIUM CYANIDE AS A SOIL FUMIGANT FOR WIREWORMS

As early as in 1914, experiments with sodium cyanide were made by Hyslop (1914). Graf during the same year drilled potassium cyanide into the soil (1914, p. 59). A few years later, calcium cyanide was found fairly effective when used in baits (Melander, 1923). Horsfall (1924) used calcium cyanide in Pennsylvania against wireworms attacking cabbage plants. Calcium cyanide was also used by Spuler (1924) and Horsfall and Thomas (1926). Experiments in the use of calcium cyanide for wireworms control were begun in Maine in 1926. The wireworms were attracted to baits and the soil was then fumigated with approximately  $\frac{1}{4}$  ounce of granular calcium cyanide per bait. The results are shown in the following table (Table 40).

TABLE 40

*Toxicity of Calcium Cyanide to Elaterid Larvae  
1926*

Bait number	Number larvae present	Number larvae killed
1	26	17
2	72	64
3	29	24
4	9	8
5	37	30
6	15	15
7	10	8
8	10	10
9	36	24
10	37	28
11	10	7
12	7	6
13	10	7
14	12	11
15	1	1
16	4	3
17	6	3
18	10	9
19	6	3
20	3	2
21	3	2
22	13	1
	366	283
		Per cent killed 77.3

Ca(CN)<sub>2</sub> applied August 17, 1926.  
Examination and counts made August 27, 1926.

The data presented in the foregoing table show that an average of 77.3 per cent of the wireworms were killed by the cyanide treatment. During 1926 the treatments were made during August and the soil was fairly loose and dry.

During the spring of 1927, calcium cyanide was placed in furrows at the rate of 200 pounds per acre. The soil was fairly wet and the application was followed by a cold rain which lasted for several days. No effect of this application of calcium cyanide on the wireworms could be found. No dead wireworms were found and there were approximately as many wireworms present in the soil 30 days after treatment as there were before.

During 1928 another set of experiments was established to test calcium cyanide as a soil fumigant for wireworms (Table 41). The soil was fairly dry and was packed so that it was firm and quite hard. After the wireworms were attracted to baits, calcium cyanide was applied at the rate of approximately  $\frac{1}{4}$  ounce per bait. The per cent killed was 53.1 as compared to that of 77.3 secured in the 1926 trials.

Wheat was planted in wireworm infested soil on May 8, 1931. Larvae of *Agriotes mancus* Say were attracted to this wheat on an

TABLE 41

*Toxicity of Calcium Cyanide to Elaterid Larvae  
1928*

Bait number	Number larvae present	Number larvae killed
1	5	3
2	14	6
3	3	0
4	10	7
5	2	0
6	3	0
7	8	5
8	4	2
9	15	9
10	7	6
11	3	2
12	8	6
13	2	2
14	4	1
15	6	1
16	2	1
	96	51
		Per cent killed 53.1

Ca(CN)<sub>2</sub> applied August 6, 1928.  
Examinations and counts made August 14 and 15, 1928.

average of  $12\frac{1}{2}$  to each yard of row. Calcium cyanide was drilled into the soil close to the row at a depth of 3 inches. No reduction in the number of wireworms present could be found. Again the weather following the application was moist and cold.

It was found in all cases where calcium cyanide was used that it did not penetrate the soil below the level at which it was placed. That is, wireworms below the calcium cyanide were not killed. The radius of the effect of cyanide was approximately 10 inches. Calcium cyanide is not effective in killing wireworms when the soil is wet and cold and it is not as effective in tightly packed soil as it is in soil of a more friable nature. It was found that the gas rising from calcium cyanide on a warm day may be very obnoxious to humans and dangerous to domestic animals.

Calcium cyanide is recommended for use in Maine when a valuable crop needs protection from wireworms or where it can be used in a small garden in connection with baiting. Unfortunately its use is most practical in summer when it is too late to protect crops from the attacks of wireworms. It may be used, however, to reduce the number of wireworms in the soil so that crops may be planted the following year with safety.

#### THE USE OF BAITS FOR THE ADULTS OF WIREWORMS

Baits for adults of the family Elateridae were used by Comstock about 1887 (1888, p. 37). Sweetened dough, freshly sliced potatoes, and clover were used. The clover was most effective. In the same publication Comstock reported good results from the use of poisons on the clover baits. Lehman (1932) refers to a number of aromatic substances tested for their attractiveness to elaterid beetles. Since 1928 clover baits have been used by the writer to collect adults of *Agriotes mancus* Say for life history and control studies (Tables 1 and 2). Attempts to poison them by the use of arsenious oxide, lead coated arsenate of lead, "copper (basic) fluoride coated," sodium arsenate and Paris green have resulted in unsatisfactory results (Table 42). Honey and molasses were also added to certain of the baits.

In general, the addition of poison to baits used for adult elaterids had a repellent effect. Whether wireworms could be con-

TABLE 42

*Baits for Adults of Agriotes mancus Say*

Nature of bait used	Date	Number of beetles taken	
		Alive	Dead
Graham flour, water and honey			
" " "	6-5-33	10	0
" " "	"	0	0
" " "	"	1	0
" " "	"	24	0
" " "	"	35	0
" " "	"	21	0
" " "	"	32	0
" " "	6-8-33	10	0
" " "	"	11	0
" " "	6-12-33	0	0
" " "	"	0	0
" " "	6-15-33	5	0
" " "	"	7	0
" " "	"	0	0
" " "	"	4	0
" " "	"	1	0
Clover	6-8-33	19	0
" " "	"	21	0
" " "	"	39	0
" " "	"	60	0
" " "	"	90	0
" " "	"	40	0
" " "	6-9-33	18	0
" " "	"	14	0
" " "	"	9	0
" " "	"	11	0
" " "	"	3	0
" " "	"	7	0
" " "	"	3	0
" " "	"	18	0
" " "	"	4	0
" " "	"	19	0
" " "	6-12-33	55	0
" " "	"	14	0
" " "	"	30	0
" " "	6-15-33	23	0
" " "	"	9	0
" " "	"	25	0
" " "	"	20	0
" " "	"	24	0
Graham flour, arsenious oxide and water*	6-12-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	1	1
" " "	6-15-33	1	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
Graham flour, lead-oleate coated lead arsenate and water	6-12-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	1†	0
" " "	6-15-33	0	0
" " "	"	0	0

\* Baits placed June 9.

† Bait had been eaten into but evidently no beetles were killed.

TABLE 42—(Continued)

Nature of bait used	Date	Number of beetles taken	
		Alive	Dead
Graham flour, lead-oletate coated lead arsenate and water	6-15-33	0	0
" " "	"	0	0
" " "	"	0	0
Graham flour, (basic) copper fluoride coated and water	6-12-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	6-15-33	0	0
" " "	"	0	0
" " "	"	0	0
Graham flour, sodium arsenate and water	6-12-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	6-15-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
Clover, Paris green and water	6-17-33	0	0
" " "	"	0	0
" " "	"	2	0
" " "	"	0	0
" " "	"	0	0
" " "	6-20-33	1	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
Clover, arsenious oxide and water	6-17-33	2	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	6-20-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
Clover, lead-oletate coated lead arsenate, water and molasses	6-17-33	0	0
" " "	"	1	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	6-20-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
Clover, copper fluoride and water	6-17-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	6-20-33	0	0

TABLE 42—(Concluded)

Nature of bait used	Date	Number of beetles taken	
		Alive	Dead
Clover, copper fluoride and water	6-20-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
Clover, sodium arsenate and water	6-17-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	6-20-33	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	0	0
" " "	"	5	0
Check clover	6-20-33	15	0
Check clover, water and honey	"	5	0
Check clover, water and molasses	"	3	0

trolled by the use of baits for the adults is largely problematical. There is no doubt, however, that the wireworm population of a given area could be reduced if the beetles could be poisoned before laying eggs. Therefore, further tests of poison baits for wireworms seem desirable.

By far the most of the beetles taken at clover baits were of the species *Agriotes mancus* Say. Many adults of *Cryptohypnus abbreviatus* Say were taken at baits of dough and some of these species were taken at clover baits (Table 43).

TABLE 43

*Baits for Adults of Cryptohypnus abbreviatus Say*

Date	Bait	Number of beetles attracted
5-26-33	Graham flour	25
5-29-33	Graham flour	140
	Clover	47
6-1-33	Graham flour	83
	Clover	61
6-3-33	Graham flour	87
	Clover	50
6-5-33	Graham flour	24
	Clover	16
6-8-33	Graham flour	10
	Clover	6
6-11-33	Graham flour	3
	Clover	1

No beetles were taken later than June 11. An occasional beetle of the species *Agriotes mancus* was taken along with those of *Cryptohypnus abbreviatus*.

#### NEMATODE PARASITES OF ADULTS OF THE WHEAT WIREWORM, *Agriotes mancus* Say

A large number of adults of *Agriotes mancus* Say was parasitized by nematodes identified as *Hexameris* sp. (Plate XIII). These nematodes were approximately 45 millimeters in length and 0.5 of a millimeter in diameter. A single nematode almost completely filled the abdominal cavity of each beetle affected. Beetles infested by this parasite have been taken in the field each year for the past four years. The number of nematode-infested beetles observed varies greatly from year to year, and more beetles affected by nematodes were found during 1930 than during any other single year. During the summer of 1930, the larvae of *Agriotes mancus* were more abundant than usual and apparently there had been a gradual increase in numbers which may have been due to the scarcity of the nematode parasites previous to that time. One of the most important factors in connection with parasitism of the adults of the wheat wireworm is the effect of egg laying of the female beetles. Such beetles as were infested did not lay eggs in the laboratory or in cages in the field. All beetles infested by nematodes died soon after the parasite emerged. This parasite, *Hexameris* sp., is the only common parasite of the adults of *Agriotes mancus*.

Another parasite was found infesting an adult of *Agriotes mancus*. These parasites, identified as a species of the genera *Rhabditis*, are of the same shape as that of *Hexameris* sp. but are much smaller. Since but a single instance of a beetle infested by *Rhabditis* sp. was taken, no opportunity was available for extensive study of this parasite.

#### FUNGI IN RELATION TO WIREWORMS

The fungus *Metarrhizium anisopliae* was found to attack wireworms during 1931. It apparently grew into the bodies of wireworms and caused them to become whitish. Several larvae were

observed to have been killed by this species of fungus during 1931 and 1932. The fungus is ordinarily more abundant in soil cages where wireworms are reared than in the field. *Botrytis bassiana* is a factor in causing the death of many young larvae of *Agriotes mancus* in soil cages. The larvae apparently become entangled in the mycelium and are unable to escape. The first and second instar larvae are affected more often than are the older larvae.

#### PREDACEOUS ENEMIES OF WIREWORMS

The horn-like exoskeleton and subterranean habitat of elaterid larvae afford considerable protection against many organisms which might otherwise attack them. Predaceous animals are among the most common enemies of wireworms. In Maine a vesper sparrow and bronze grackles have been observed to follow the plow and eat wireworms which were turned out. Hyslop (1915, p. 26, 27) lists many birds as destroying elaterid larvae and adults. Hyslop says, "Probably the most important factor in keeping wireworms in check is birds." It is probable that numerous adults and larvae of Elateridae are consumed by birds in Maine. Our evidence is largely based on the presence of birds feeding in fields where larvae and adults are abundant. Toads, frogs, and reptiles are recorded as destroying adult elaterids (Thomas, 1931, p. 158-159).

Among the lower groups of animals, members of the order Acarina or mites are most commonly found on elaterid larvae. Mites found on larvae of *Agriotes mancus* Say and *Melanotus* sp. were identified by Dr. Ewing of the National Museum as mites of some species of Tyroglyphidae. He explained that the mites are hypopi, that is, non-feeding migratory nymphs. This being the case it could hardly be expected that the mites affected the larvae adversely.

Numerous adults of *Agriotes mancus* Say have been found destroyed except for the wings. At first this could not be accounted for, but finally spiders were observed feeding on the beetles. One of these was identified as a female of *Xysticus ferox* Keys. Carabid beetles, *Poecilus lucublandus* Say, have been taken in the larval stage feeding upon larvae of *Agriotes mancus* and the adults of this species ate both the larvae and adults of *Agriotes mancus* in soil cages. The staphylinid beetle, *Staphylinus badipes* Lec., was also taken in the act of eating a larva of *Agriotes mancus*. These beetles

as well as those of *Poecilus lucublandus* are commonly abundant in the fields where wireworms are present.

## SUMMARY

Wireworms and their control were much discussed in the early entomological literature of America and later workers have added much useful information on the subject. The study of wireworms is especially difficult because of the long time required by most species to complete their life history, and because their subterranean habitat conceals them from observation. Consequently, many facts concerning wireworms are/yet unknown.

Growers of flowers, vegetables, and field crops suffer large annual losses because of wireworm injuries. Probably \$1,000,000 would be a conservative estimate of the average loss caused annually by these insects in Maine alone.

A list of 48 plants is recorded as being attacked by wireworms in the State and there may be many other plants that should be included. Potatoes are more severely injured than any other crop grown in Maine.

Wireworms are the larval stage of beetles of the family Elateridae and are commonly called click beetles or skipjacks. The name is applied because they are able to skip into the air with a clicking sound when placed upon their backs.

Wireworms are distributed over almost all of the farming area of the United States and are also prevalent in many other parts of the world. They infest a large section of the farming area of Maine, but are relatively less abundant in the potato growing areas of Northern Aroostook County than elsewhere.

Fifty known species of Elateridae are recorded from Maine. Of these, *Agriotes mancus* Say is the most important from the standpoint of the amount of injury caused to crops. Wireworms belonging to the genus *Melanotus* rank second, those belonging to the genus *Ludius* rank third, and wireworms of the genus *Limonius* are probably fourth in losses caused to agricultural crops.

The species of Elateridae which have been taken in the larval stage in Maine are described. Adults of important species are also described and some of their morphological characters are illustrated. Emphasis is placed on the morphology of *Agriotes mancus* Say as

the most important Maine species. Descriptions of eggs and pupae are included for certain species.

The life history of *Agriotes mancus* Say requires at least three years for its completion and some larvae do not pupate until August of the fourth year. The life histories of other species are imperfectly known.

Climate is probably an important factor in determining what species of Elateridae inhabit Maine. The type and moisture content of the soil were found to be important to the survival of wireworms. They have not been found dead following winters of low temperature, and neither have they been found in great numbers in the frozen soil. Apparently most of them hibernate at a level in the soil where extreme winter temperatures do not exist. Snow coverage is important in preventing soil temperatures from becoming low.

Wireworms injure plants in several ways. They destroy planted seed, older plants and the mature crop. The greatest injury to crops in Maine is that caused to potato tubers before they are harvested in the fall.

It is important to know whether or not wireworms are present in the soil before crops are planted. If they are present, the number in the soil has a bearing on the possibility of the successful production of crops. For these reasons the taking of the wireworm census is advocated. This has been done by sifting the wireworms from soil samples.

There was found to be a relation between the number of wireworms present in the soil and the percentage of potatoes injured, when grown in the infested soil. In general, as the wireworm population increased the percentage of tubers injured also increased. This is true to a limited extent also for the relation of the wireworm population to the number of punctures per tuber, but in this relation there were certain inconsistencies found in the data.

Cultivation was found to be a practical method of controlling wireworms. It required from 1 to 4 years to reduce the wireworm population to a point consistent with the safe production of susceptible crops. The time required to control wireworms by cultivation depended upon the initial infestation. Approximately 45 per cent of the wireworm population was found to be eliminated by one year of cultivation, 65 per cent by two years, and 80 per cent by three

years of continuous cultivation of the soil. Clean cultivation was also found essential to wireworm control.

The wireworm population was apparently but little more reduced in soil kept fallow than it was in soil in which cultivated crops were grown.

The effect of fall plowing on wireworm populations is somewhat problematical. However, it does not entirely eliminate wireworms from the soil. Probably the greatest value of fall plowing is not that great numbers of wireworms are directly killed by the mechanical action of plowing, but rather that there is a sudden change caused to their environment which may affect their hibernation unfavorably.

Field trials of fertilizer for its effect on wireworms have led to the conclusion that it has little value in wireworm control beyond the fact that it may force to maturity a crop which might otherwise succumb to wireworm attacks.

The status of the direct effect of drainage on wireworms is somewhat doubtful, although certain species are not as abundant in drained soil as they are in undrained soil of the same type. Drainage makes it possible to control wireworms by cultivation in certain areas which could not be thoroughly cultivated were they not drained.

Utilization of the best soil is recommended for preventing wireworm injury to susceptible crops. This applies especially to potatoes, for the best potato soil is seldom heavily infested by wireworms.

A short crop rotation can be used to advantage in preventing reinfestation by wireworms. Hay crops or long standing grain crops are favorable to wireworms and should be omitted as much as possible from the rotation. A resistant green manure crop such as crimson clover or buckwheat can be used in the rotation with crops susceptible to wireworm injury. Thus reinfestation can be prevented after wireworms have once been controlled.

There is a difference in the susceptibility of crops to wireworm attacks. Potatoes are among those most susceptible. Corn is somewhat less susceptible than potatoes, and broadcast grain, clover, and grass crops are able to withstand severe wireworm infestations. Beans and peas are also somewhat resistant and may be grown in soil containing a considerable number of wireworms.

Naphthalene and kainit were both found to be toxic to wireworms when used in large amounts. However, consistent results from their use in the field have not been obtained.

Magnesium chloride and magnesium sulfate were toxic to wireworms under certain concentrations and conditions.

Paradichlorobenzene, calcium chloride, sodium chloride, and lime did not prove satisfactory in controlling wireworms when tried under field conditions. Mercurous chloride, sulfur, and carbon tetrachloride, when used under laboratory conditions, were found to be toxic to wireworms in varying degrees. Powdered tobacco applied under field conditions at the rate of 1000 pounds per acre apparently had little effect on wireworms, and cyanamid was also ineffective when used at the same rate.

Sprouting wheat proved to be the most attractive of several baits used for wireworms. The addition of molasses increased the attractiveness of graham flour baits. Poisonous substances added usually decreased the attractiveness of the baits used.

Calcium cyanide was effective as a soil fumigant for elaterid larvae. The conditions of soil and atmosphere are important factors in the use of this substance. Calcium cyanide should be used in summer when the soil is dry and warm. Hard or packed soil can not be successfully fumigated.

Baits of clover, cut and placed on the soil, were the most attractive of those used for beetles of *Agriotes mancus* Say. Poisons added to baits for the adults also acted as repellents in most cases. Beetles of *Cryptohypnus abbreviatus* Say were attracted to baits of graham flour dough.

The most important parasite of *Agriotes mancus* Say found was a nematode, *Hexameris* sp. This parasite lives in the body of the beetle and apparently prevents the eggs of the host from becoming fully developed.

Fungi occasionally attack wireworms but are probably not an important factor in their abundance.

Birds are known to eat wireworms. Carabid beetles and their larvae as well as staphylinids occasionally attack and kill wireworms. Spiders sometimes kill the adults of *Agriotes mancus*. On the whole, predaceous enemies are valuable as checks on wireworm abundance, but they can not be depended upon to effect complete control.

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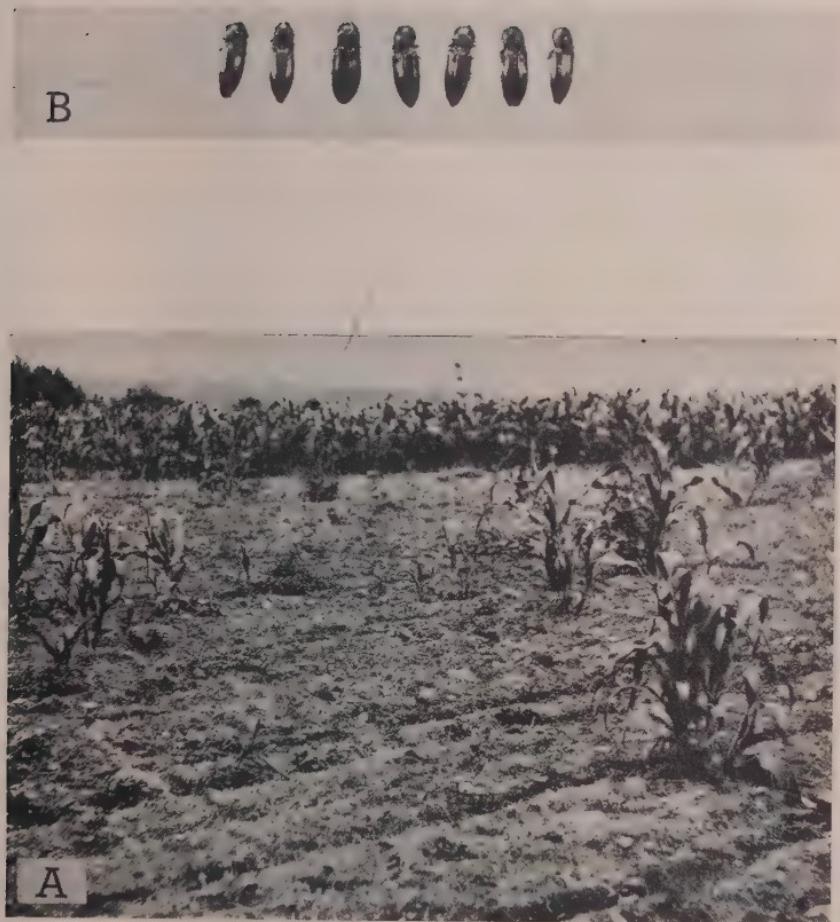


PLATE I

- A. Corn field showing damage done by elaterid larvae.
- B. Adults of *Agriotes mancus* Say.

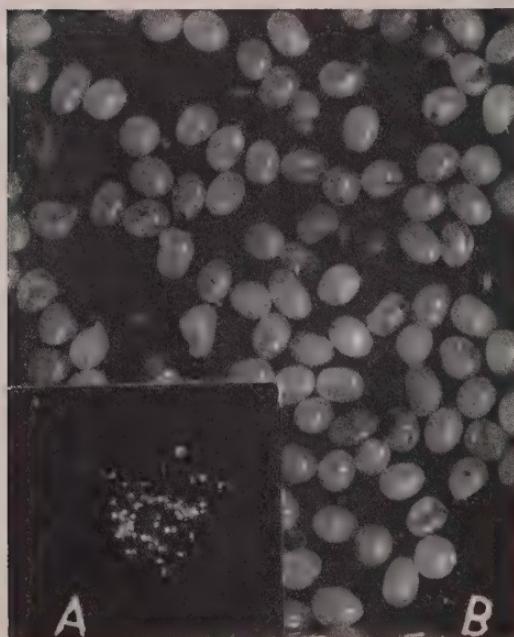


PLATE II

- A. Eggs of *Agriotes mancus* Say.
- B. Eggs of *Agriotes mancus* Say.
- C. Pupae of *Agriotes mancus* Say.

PLATE III  
Sticky shield trap.



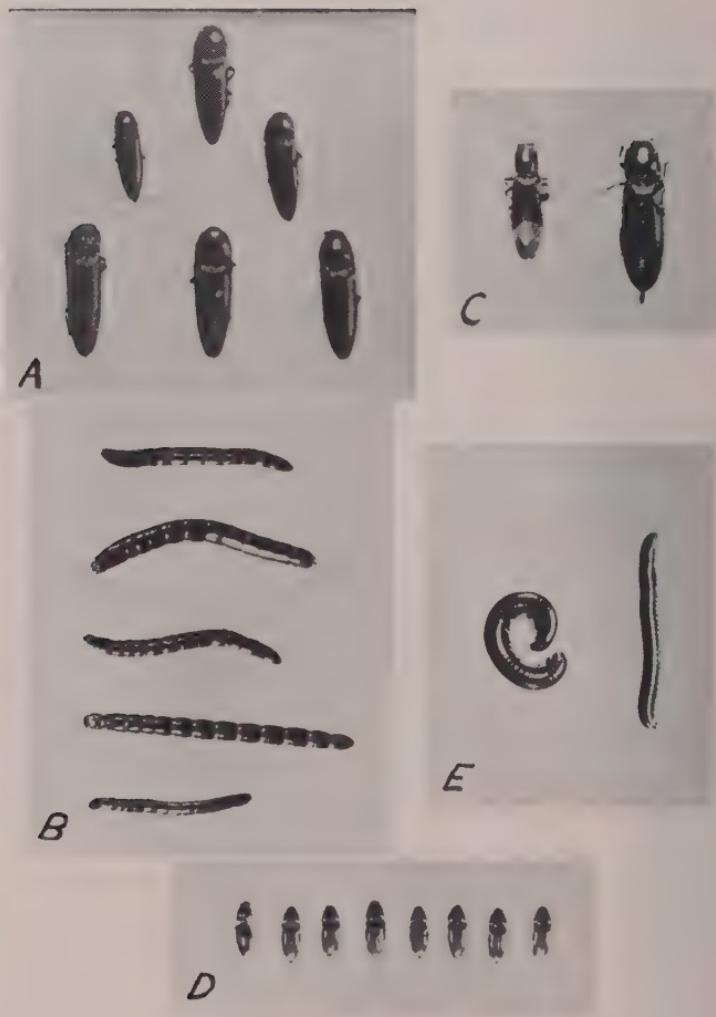


PLATE IV

- A. Beetles of the genus *Melanotus*.
- B. Larvae of the genus *Melanotus*.
- C. Adults of *Ludius cylindriformis*, male and female.
- D. Adults of *Cryptohypnus abbreviatus* Say.
- E. Millepedes.

PLATE V  
Potato plants injured by wireworms.



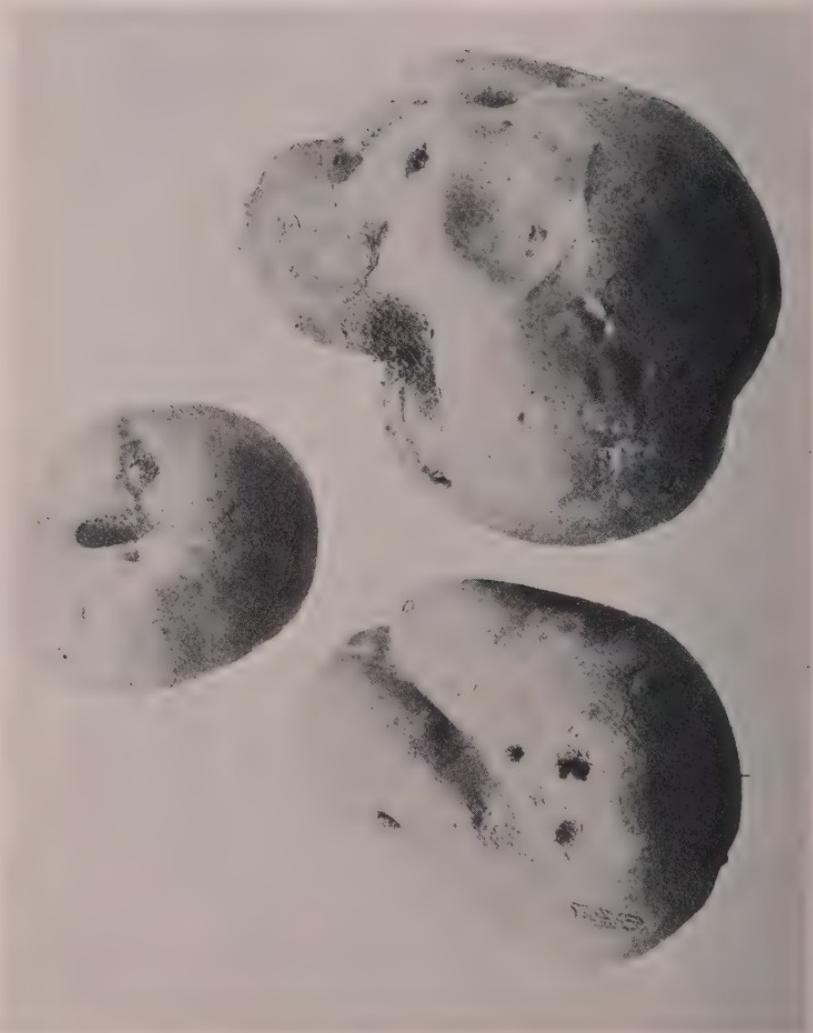


PLATE VI

Early season injury to potato tubers.



PLATE VII

Late season injury to potato tubers.

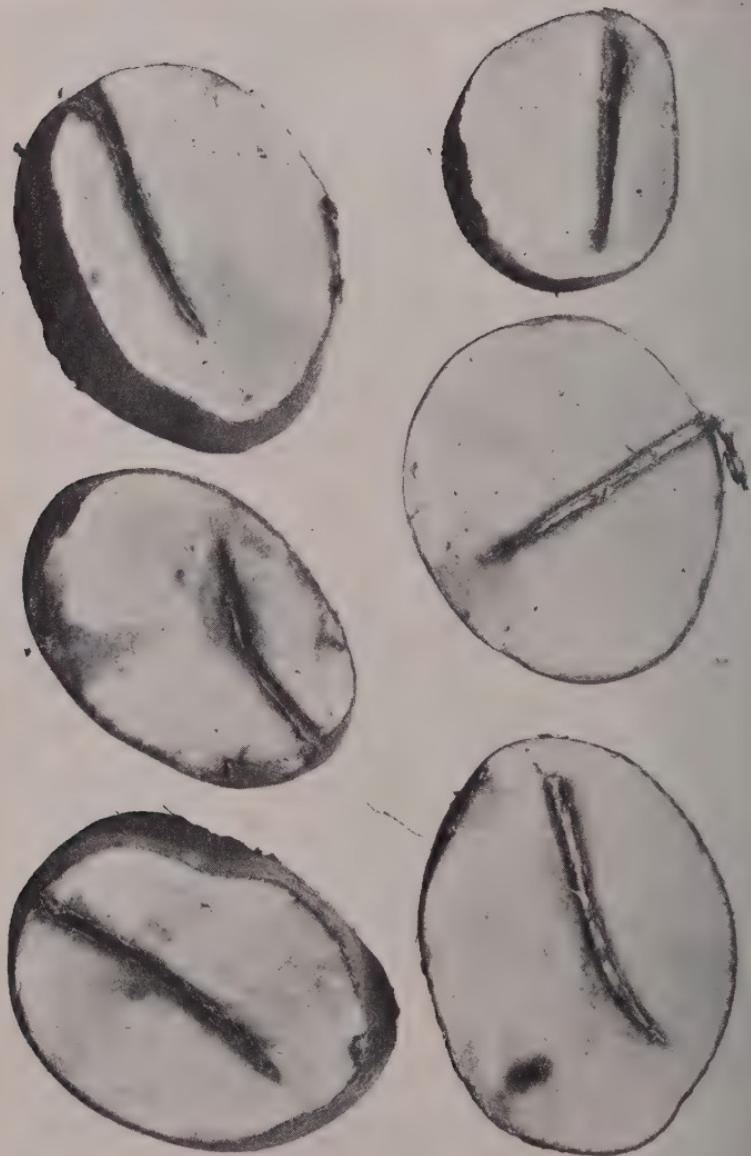


PLATE VIII

Grass rhizomes in potato tubers.

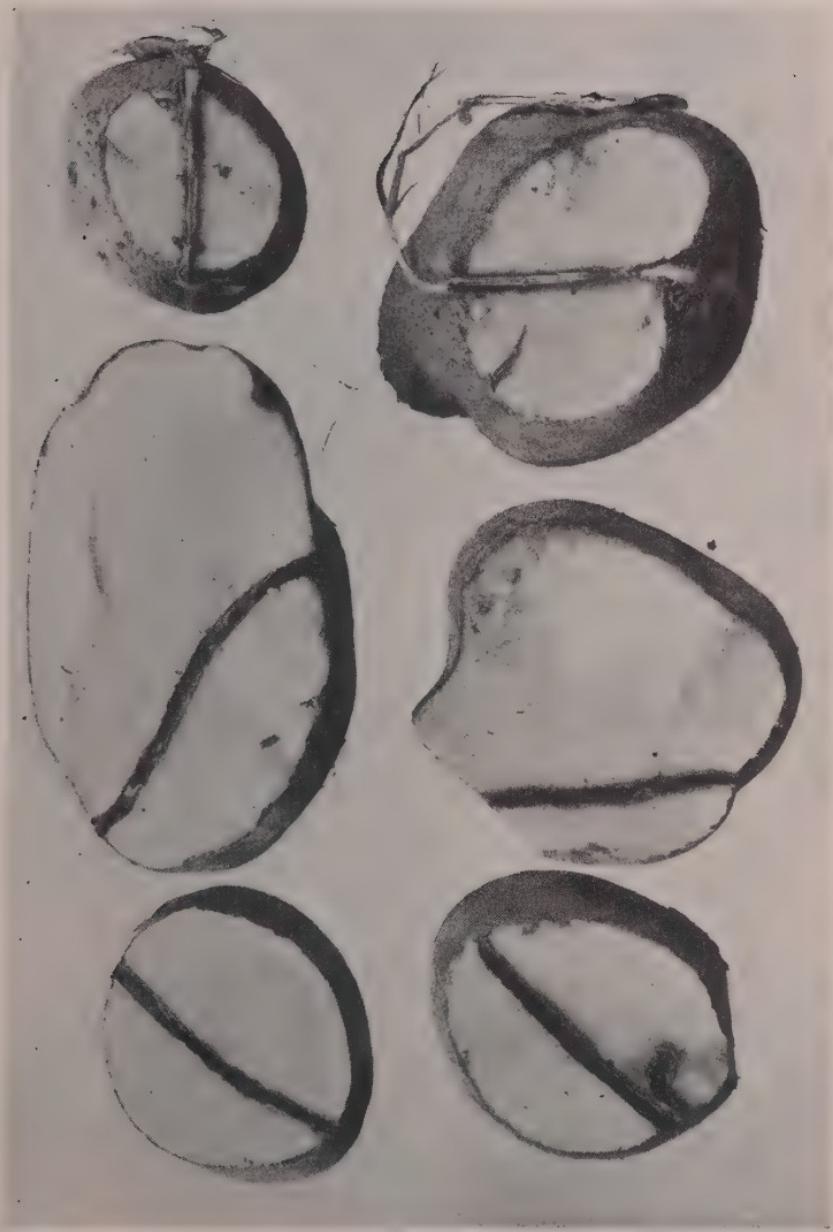


PLATE IX

Grass rhizomes in potato tubers.



PLATE X

Potato tuber injured by Rhizoctonia.



PLATE XI

- A. Corn kernels injured by wireworms.
- B. Growing corn injured by wireworms.



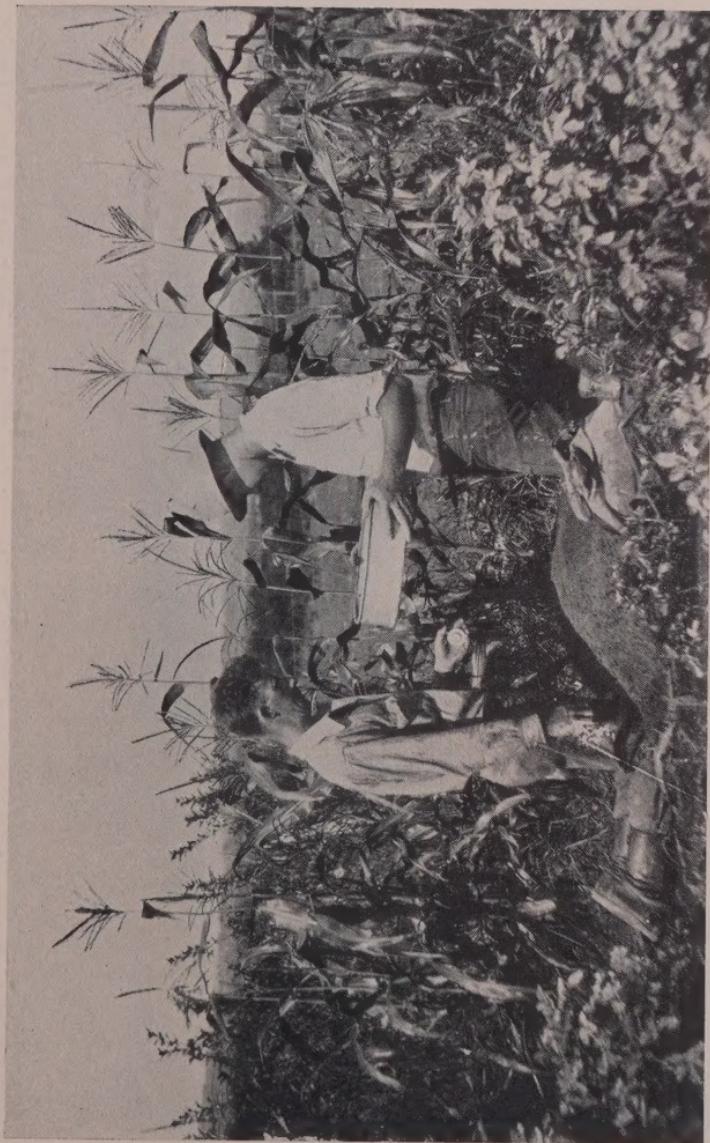


PLATE XII

Sifting soil for wireworms.



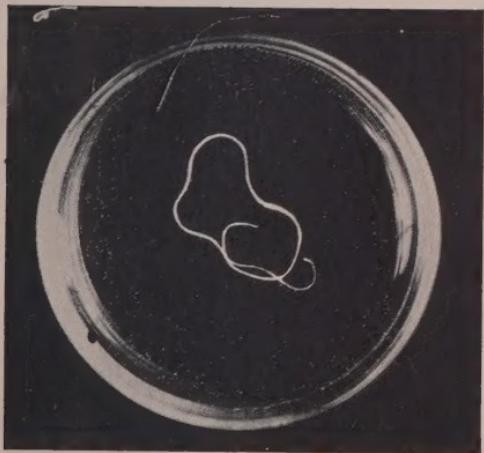


PLATE XIII

A nematode parasite of adults of *Agriotes mancus* Say.

